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التاريــــخ: / /

نموذج رقم (18)
اقرار والتزام بالمعايير الأخلاقية والأمانة العلمية
وقوانين الجامعة الأردنية وأنظمتها وتعليماتها
لطلبة الماجستير

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عنوان الرسالة:
COMPUTER PROGRAMMING AND PERFORMANCE STUDY
OF A POTENTIAL RESIDENTIAL APPLICATIONS OF SMALL-SCALE
HBRID WIND-SOLAR OWER SYSTEMS

اعلن بأنني قد التزمت بقوانين الجامعة الأردنية وأنظمتها وتعليماتها وقراراتها السارية المفعول المتعلقة باعداد رسائل الماجستير عندما قمت شخصيا" باعداد رسالتي وذلك بما ينسجم مع الأمانة العلمية وكافة المعايير الأخلاقية المتعارف عليها في كتابة الرسائل العلمية. كما أنني أعلن بأن رسالتي هذه غير منقولة أو مستلة من رسائل أو كتب أو أبحاث أو أي منشورات علمية تم نشرها أو تخزينها في أي وسيلة اعلامية، وتأسيسا" على ما تقدم فانني أتحمل المسؤولية بأنواعها كافة فيما لو تبين غير ذلك بما فيه حق مجلس العمداء في الجامعة الأردنية بالغاء قرار منحي الدرجة العلمية التي حصلت عليها وسحب شهادة التخرج مني بعد صدورها دون أن يكون لي أي حق في التظلم أو الاعتراض أو الطعن بأي صورة كانت في القرار الصادر عن مجلس العمداء بهذا الصدد.

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COMPUTER PROGRAMMING AND PERFORMANCE STUDY OF POTENTIAL RESIDENTIAL APPLICATIONS OF SMALL-SCALE HBRID WIND-SOLAR OWER SYSTEMS

By
Banan Mohammed Alkasasbeh

Supervisor
Dr. Mahmoud Hammad, Prof

This Thesis is submitted in Partial Fulfillment of the Requirements for the Master's Degree in Energy Management Engineering.

Faculty of Graduate Studies
University of Jordan

June, 2011

COMMITTEE DECISION

This Thesis (Computer programming and Performance Study of Potential Residential Applications of Small-Scale Hybrid wind-solar Power Systems) was successfully defended and approved on May 3, 2011.

Examination committee	**Signature**
Dr. Mahmoud Hammad (Supervisor) Prof. of Mechanical engineering.	
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Dr. Ahmad Sakhriah (Member) Assis.prof.of Mechanical enegineering.	
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Dedication

- To my father and my mother.
- To my life mate, my husband, Dr. Bahjat altakhaineh, who has given his unlimited and unconditional love and care, without his support, I could not succeed.
- To my daughter, SAMA, the most beautiful flower in my life grove.

Acknowledgement

I am overjoyed that this thesis is finally completed. It has been at times a rough and hard journey. At times it was difficult to continue, but through it all the achievement of accomplishing this difficult task was ultimately worth all the work and at this moment I am very proud.

I would like to thank all people who have made this work possible. First, I would like to express my sincere gratitude and deepest appreciation to my supervisor Dr. Mahmoud Hammad for his substantial inspiration and guidance throughout this study.

Dr. Hammad gave me unlimited assistance and help, not only during preparing this study, but also through all my graduate studies. Through his guidance, I have gained invaluable experience and insight related to the field of renewable energy. During my work with Dr. Hammad, I have benefited tremendously from the depth and breadth of his knowledge which made me a better researcher.

Also I would thank the members of discussion committee Dr.Adnan Jaradat, Dr. Ahmad Sakhriah, and Dr. Handri Ammari for their efforts to assess this study and introduce their knowledge to improve and enhance any deficiency since that the completion is for Allah.

I would like to thank eng. Rula Alkhalid from the information technology college in the University of Jordan, for her assistance in building the computer program using JAVA programming language.

Also, a special thank to Dr Bayan abu Shawar from Arab Open University for her assistance in the computer programming stage.

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Abbreviations and symbols.

Abbreviation	Terminology
CO_2	Carbon dioxide
GHG	Green house gases
RPS	Renewable portofolio standard
WPS	Wind-PV system
ANN	Artificial Neural Network
MW p	Mega watt (peak)
BOS	Balance of system
DC	Direct current
AC	Alternating current
PV	Photo voltaic
WWEA	World wind energy association
JMD	Jordanian metrological department
MEMR	Ministry of energy and mineral resources
WPD	Wind power density
Ho	Horizontal extraterrestrial radiation
Vo	Vertical extraterrestrial radiation
Ep	Energy delivered by PV
K	Shape factor
C	Scale factor

COMPUTER PROGRAMMING AND PERFORMANCE STUDY OF POTENTIAL RESIDENTIAL APPLICATIONS OF SMALL-SCALE HBRID WIND-SOLAR OWER SYSTEMS

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ABSTRACT

Renewable energy is an attractive solution to the world's energy challenges. Both solar and Wind energies are considered to be the major resources of renewable energy in Jordan. As they are abundance and may produce energy at relatively affordable cost, therefore, they are likely to be an important component of future power generation schemes.

This study examined in details the potential of using hybrid (wind – solar) power system in a small scale for residential applications at different sites in Jordan. Based on the wind speed data gathered by Jordan Meteorological Department, JMD, and calculated solar radiation this simulation was conducted. The chosen sites for this study were: Amman, Aqaba, Dead Sea, Ajloun, Irbid, and Alkarak.

Electrical energy load for a typical house was calculated and the maximum consumption which was approximated to 9 kWh/day was used in the design of the system.
According to the wind data collected by the JMD only three sites proved to posse's Applicable wind for use. These spots were: AL-karak, Irbid and Ajloun.

All sites were served by a suitable PV array of the number of required panels and the required number of batteries to serve as stand alone system.

It was found that the difference in solar energy intensity at the different sites is so small, Single design can operate for all sights.

With respect to wind energy, after choosing a wind turbine of rated output power of 1000 W. The Weibull method for calculating the yearly probable hours of wind velocities to exceed the cut in velocity, and the yearly average wind speed, Then based on the results, the using of wind energy in that site was determined to be Applicable or not.

The study revealed that the Applicable sites are: Alkarak, Irbid, and Ajloun with yearly average wind speeds 7.37, 6.61, and 7.09 m/s, and average output power of 3595, 2965, and 3229 Wh/day respectively.

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Chapter One

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Introduction

Chapter one

Introduction

1. Forward

In the last two decades, renewable energy became the most important core of many researches and studies which aimed to improve and enhance many technologies and strategies to take the paramount benefiting from the different forms of renewable energy such as: wind energy, solar energy, biomass energy …etc.

The expectation of oil and gas depleting, unstable industry and pricing of oil, and the growing concerns about global warming, all of these have made it inevitable to seek alternative energy resources.

There are many and different resources of renewable energy, but the main issue here is how to use those resources, which are dependent on the weather conditions, in the most optimal and efficient way.

These resources are function of: the region, environment, and various other uncontrollable factors. Therefore, it is very important to consider the performance of solar cells and wind generators while taking into account the variability of the energy sources. (Acosta, 2009)

If solar modules, battery, and wind turbine technologies keep improving and prices keep dropping. Wind - photovoltaic systems with battery storage will soon be a viable support in transmission and distribution losses reduction such as: peak shaving, fuel saving, voltage support, and pollution reduction. (Giraud and salameh, 2007)

Solar energy considered to be one of the most important resources since the earth is exposed to sun for many billions of years, so the exploitation of this radiation will be very useful especially to generate electricity for different usages in the life.

Today, there are large solar energy farms which are filled with solar panels to exploit this kind of energy. (Acosta, 2009).

Wind energy is another very important type of renewable energy that can be used to generate electricity. Both wind and solar energy considered to be site-dependent, non-polluting, non depletable. (Belfkira et.al, 2008).

There are many plants which they are using these two types of energy in a hybrid system in order to achieve the optimum amount of energy and generated electricity. For both systems, the changes in the meteorological conditions (solar irradiation and average annual wind conditions) are considered to be very important, since the performance of solar and wind energy systems depend on the climatic conditions of the location. The power generated by a photovoltaic system is highly dependent on weather conditions. For example, at night and when the clouds cover the sky, a photovoltaic system would not generate any power. In addition, it is difficult to store the power generated by a photovoltaic system for future uses. The most effective solution of this problem that a photovoltaic system can be integrated with other alternate power sources such as wind turbines and/or storage systems, such as batteries.

A system that can simultaneously capture solar and wind energy has an advantage over others due to the fact that the two systems will be a complement to each other.

So, in a time when the cost of energy is constantly on rise, a hybrid power system which produces power using sun and wind provides a viable option of renewable energy.

These days, research and studies to develop the hybrid power systems has become an important factor to solve and mitigate the serious problems of energy. Also to find solutions to the environmental damage that the utilization of fossil fuels creates due to

the emission of carbon dioxide (CO_2) and its effect in global warming. In spite of the relatively high initial investment cost, a hybrid power system could provide great benefits, especially when the country or the region has an abundant sun radiation and wind during the year.

1.1 Significance of the study:

In this work the potential of using hybrid energy systems in the residential applications and its performance will be studied since that these applications are very important and provide many benefits for any household and small businesses. For a household located in an area with electrical infrastructure, a hybrid power system with current technology does not provide much energy savings. The benefit becomes apparent in natural disaster or blackout situations where there is no electricity available from the grid. Even in these scenarios, there are several other more cost effective alternatives such as gas powered generators. However, in cases where gasoline or diesels are not readily available, a hybrid power system will be very beneficial. Families in remote areas where there is no electrical infrastructure will greatly increase their quality of life with a hybrid power system. This system can be utilized to power a couple of lights and even a refrigerator that will keep vital food and medicine from spoiling.

1.2 Problem of the study:

The rapid growth of solar and wind powers is due in part to favorable global political climate towards these energies, efforts to reduce carbon dioxide (CO_2) and greenhouse gases (GHG) emission and other power plant pollutants, global awareness of climate changes, and the urgency to develop renewable energy sources. Other factors such as

lucrative tax incentives and legislations mandating national renewable energy standards have accelerated the march towards solar and wind energies.

The Kingdom of Jordan is considered an emerging country in the Middle East; it has almost no natural resources. The country imports most of its oil needs from neighboring countries at international market prices. Oil and gas imports creates huge burden on the country's national economy. Electricity is generated by burning imported gas and oil. Limited generation from wind turbines and biogas do exist. When oil prices rose to extremely high levels last summer, Jordanians experienced continuous increases in electricity prices. It is urgent and essential to deploy other alternatives for electrical generation, which is the use of solar and wind energy for electrical generation.

The problem lies in the fact that people have not been presented with other options of producing electricity for use in their homes or businesses. Current sources of energy do not provide a practical solution to relieve the cost of electricity. High energy costs require the design of systems that can convert the abundance of sunlight and wind into electricity and at the same time reduce the consumption of fossil fuels. These systems must be able to self regulate their energy storage and energy usage using smart controllers with minimal human interaction.

This research aims to study the performance and the potential use of hybrid energy systems in the residential applications of small-scale systems in different sites in the Hashemite kingdom of Jordan which they are: (Amman, Aqaba, Al-karak, Ajloun, Irbid, and Dead sea), also it tries to simulate this system by using JAVA language program.

1.3 Thesis outlines:

This thesis consists of eight chapters. This first chapter gives an introduction to the renewable energy in general and introduces the problem of the study and its significance.

Chapter two reviews the relevant literature and summarizes the existing theoretical background for the above subjects.

Chapter three focuses on solar energy and photo voltaic cells also its history, description, and their types.

Chapter four focuses on wind energy and will give an introduction and background about the wind turbines and their types and sizes.

Chapter five gives description of the mathematical model and the method of data collection and preparation.

According to computer simulation chapter six will give a clarification about the computer program.

Chapter seven will focus on the results also a discussion about these results.

Chapter eight will focus on the economical parts and view the economic study.

Finally, the conclusions and future work will be set out in chapter nine.

Chapter Two

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Literature Review

Chapter 2

Literature Review

2. Introduction

The usage of renewable energy to satisfy the power demand has been increasing over the last years. The need of producing a cleaner energy to reduce the greenhouse gases that create environmental problems like global warming, a decrease in the cost of the materials used to develop this technologies and the increment in the cost of the fossil fuel among others, are some of the reasons that have been pushing this increment (Jimenez-brea, 2009).

The concept of solar and wind energies dates back to nearly 7,000 years ago, However, in the late 1800s the Danes developed the first wind turbines to produce commercial electricity. (Halasa, 2010).

In the US, some states have enacted "renewable portfolio standard (RPS) law that requires utilities to sell a certain percentage of the energy from sustainable energy sources within reasonable stipulated times. Even though Europe and North America have the largest installed capacity of wind turbine, China, India, and developing world have the biggest potential for wind power. (Halasa, 2010).

2.1 Wind-PV systems literature review

This section will focus on the new literature of hybrid (wind/PV) energy research in Jordan and worldwide, these researches will be arranged according to their issued date.

Arutchelvi and Arul (2006), investigated a new idea of a dc–dc converter with a dual control strategy of peak power tracking when the battery is connected and in voltage control mode in the absence of the battery. The battery charging and discharging regimes have been distinctly identified for variations in irradiations and shaft-torque

conditions; it was observed that the controller is able to track peak power for any condition of irradiation and wind speed. Also that the controller maintained a perfect power balance and ensured a constant voltage across the inverter when the battery was absent. The battery charging and discharging regimes for varying conditions of irradiations and torques have been successfully plotted for a sample system. The developed model can easily be used to analyze a PV-IG (Photo Voltaic-Induction Generators) scheme of any rating.

Giraud and salameh (2007) analyzed the combined effects of random clouds and wind gusts on a grid-linked rooftop wind-photovoltaic system (WPS) with battery storage. The wind speed and the solar radiation are considered as the sole sources of power whose variations influence the system variables. Here, the system responses are predicted with artificial neural networks (ANN) which allowed circumventing two major problems: parameter uncertainty and system non-linearity, which could be high for large systems with multiple components placed in unpredictable environment characterized by turbulent movement of wind and random cloud passages. This study reveals that in gusty winds and under cloud shadowing, the system owes greatly its stability to the capacitive property of the battery bank and the inverter voltage control. This almost was a constant voltage at the input of the grid-linked inverter allowed a highly stable voltage at the common point with the utility. The battery backup manages power deficit and surplus to maintain a constant scheduled delivery to the utility use.

Belfkira et al. (2008) used a methodology to calculate the optimum size of a stand-alone hybrid wind/photovoltaic (wind/PV) system. Data of wind speeds, solar irradiances and ambient temperatures were collected for six months and recorded for every hour of the days .The mathematical modeling of the principal elements of the

hybrid wind/PV system was exposed showing the main sizing variables and a deterministic algorithm was used to minimize the life cycle cost of the system while guaranteeing the satisfaction of the load demand. The main Results of this study showed clearly the dependence of the optimum number of wind turbines, PV panels and batteries on the site wind and the site solar radiation, load profile and the specifications and the related cost of each component of the hybrid system.

Acosta (2009) provided an experimental study to understand the small-scale hybrid power systems. Experiments were conducted in 2009 to identify potential applications of renewable energy in residential and commercial applications in the Rio Grande Valley of Texas. Acosta found that carefully constructed solar-wind power systems can provide people living in isolated communities' sufficient energy to meet their basic power needs consistently.

Dihrab et al. (2009) made a feasibility study of using the renewable resources for power generation.They proposed a hybrid system (PV and Wind turbine) for grid connected applications for four cities in Jordan which they were: Amman. Der alla, Ras Muneef, and Aqaba.

The results showed that Jordan can use the solar and wind energy to generate power enough to power some villages in the desert or in the rural areas. The results also indicated how the locations can affect the total output for the system and that the better location for such a system was in Ras Muneef .Difference in wind energy is considerable, but for PV there is no differences can be reported between the selected cities.

Taskin et al. (2009) made a study based on the modeling of two emerging electricity systems based on renewable energy: photovoltaic power and wind power The study presents an evaluation of combined solar and wind systems for highway energy

requirements such as lighting, SOS's, billboards,.. etc. Savonius Wind Turbines were used for this study. Savonius turbine performance tests were carried out to determine its experimental parameters. Also, cost optimization and feasibility of the combined system were evaluated. The main results of this research were the computation of optimization, optimum number for solar panels, wind turbines, and required batteries, were calculated for a one km highway illumination system.

Halasa (2010), discussed the electrical power generation using solar- and wind-energy for the country of Jordan and discussed different control methods to link with the national grid. The results into installing windmills farm in the mountainous area in the north, where wind speed proved to be viable, while the eastern desert is suitable to install solar power stations. The cost for the windmill farm to produce 100-150MW for 20 hours per day was US$290 million. The cost of the solar power station to produce 100MW for 8 hours per day was US$560 million. The production cost per kWh (in US cents) is 2 cents for the windmill and 7.7 cents for the solar. The conventional production cost 9.5 cents projected when the price of oil is US$100 per barrel. For reliable energy systems, hybrid power production is essential. Results of this study showed the costs are highly unreliable and the wind and solar costs are higher than calculated by this study.

Heide et al. (2010) studied the Seasonal optimal mix of wind and solar power since that the wind power generation is much stronger in winter than in summer, and the opposite is true for solar power generation, Those two opposite in behaviors systems are able to counterbalance each other to a certain extent, they can follow the seasonal electrical load curves. The results showed that for 100% renewable Europe the seasonal optimal shares were 55% wind and 45% solar power generation. For less

than 100% renewable scenarios the share of wind power generation increased and that of solar power generation decreased.

2.2 This work

Only grid connected commercial applications were discussed for Jordan. So this study will investigate a small-scale hybrid power system as stand alone system for residential applications. Mathematical modeling and computer simulation will be used. Performance study of the unit will be carried out and a new algorithm will be programmed using JAVA to solve this model.

Chapter Three

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PV Power Systems

Chapter Three

Photo voltaic power systems

3. Introduction:

As the case of other generating sources of electricity, photo voltaic systems also require a fuel in order to generate electricity. As inferred from the name, photo voltaic, which is a combination of the Greek word "photo" which means light and voltaic which means electric, the fuel needed for this generating system is sunlight. In a nutshell, photo voltaic means light to electricity. Thus a designer of photo voltaic system must be able to ascertain the amount of sunlight that exists per given area at different locations and times throughout the year.

3.1 Background of photo voltaic:

The world-wide demand for solar electric power systems has grown steadily over the last 20 years. The need for reliable and low cost electric power in isolated areas of the world is the primary force driving the world-wide photovoltaic (PV) industry today. For a large number of applications, PV technology is simply the least-cost option. Typical applications of PV in use today include stand-alone power systems for cottages and remote residences, navigational aides for the Coast Guard, remote telecommunication sites for utilities and the military, water pumping for farmers, and emergency call boxes for highways and college campuses, to name just a few. An example of a centralized photovoltaic system is presented in Figure 3.1.

Figure 3.1 Centralize Photovoltaic System, (RETScreen).

Significant growth in demand for PV systems is expected to occur in developing countries to help meet the basic electrical needs of the 2 billion people without access to conventional electricity grids. In addition to this demand for cost effective off-grid power systems, environmental and longer-term fuel supply concerns by governments and electric utilities are beginning to help accelerate the market for demonstration programs PV systems connected to central electric grids in industrialized countries. During the year 1999, the estimated annual world-wide shipments of photovoltaic modules by manufacturers were approximately 200 megawatts (MWp) with annual PV industry sales exceeding the 3 billion dollar mark for complete systems. In comparison, roughly 23 MWp were shipped during 1985 which means that the industry has grown over 850% in just 14 years. This growth has lead to an installed base of PV electric generation capacity of greater than 1,000 MWp world-wide at the beginning of 2000. (RETScreen).

3.2 Descriptions of photovoltaic systems:

Photo voltaic systems (PV) are solid-state semiconductors consists of two major subsystems of hardware: photo voltaic modules and the balance of system (BOS). Photo voltaic modules house an array of solar cells that deliver direct current (DC) power, whereas (BOS) equipment include components needed for mounting, power conditioning and site- specific installation.

Balance of system components can be classified into four categories which are shown in figure (3.2):

1- PV array which is a number of solar panels connected in series and /or in parallel. It converts sunlight into direct current (DC) electricity. Typical conversion (solar energy to electrical energy) efficiency for common crystalline silicon modules are about 15%. (Jaber, 2007)

   The PV modules are amounted on metallic support structure south facing and tilted at sights latitude. Also PV array should be avoided the shading from surrounding obstructions.

2- Charge controller which is an electronic device which prevent over charging that result in out-gassing of the battery, as well as keeping electrical storage in the battery from discharging to the solar module at night.

3- Inverter which changes the DC solar power into usable 220 volt alternating current (AC) electricity which is used in household appliances and lighting. It accepts two or more different power sources to be utilized in the system, such as diesel generators, utility grid, batteries,…..etc.

4- Batteries, it stores electricity in order to be utilized during the nights and cloudy days, the batteries also is required for critical loads. The solar batteries are used as part of stand alone solar PV system. (jaber, 2007)

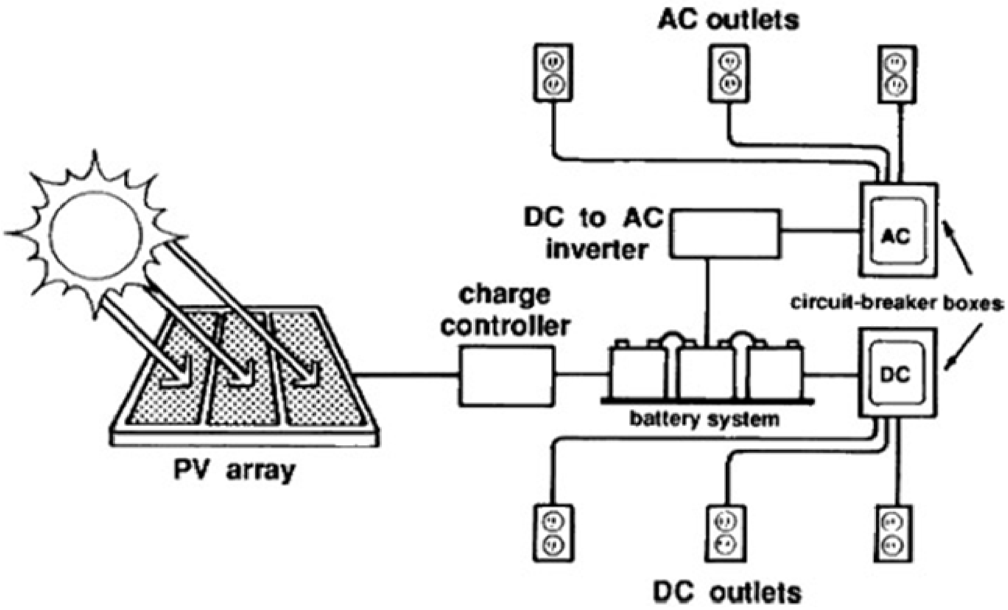

Figure 3.2 Main components of BOS, (Jaber, 2007).

3.3 Photo voltaic technology:

The solar cell which is typically 10cm×10cm square is considered to be the basic element of photovoltaic technology. It is constructed by joining two dissimilar layers of semiconducting materials, referred to as p-type (positive) and n-type (negative) semiconductors. "Doping" a semiconductor, usually crystalline silicon, with an impurity (typically boron) creates a deficit of negatively charged electrons, producing a "p-type" semiconductor; figure 3.3 shows the basic principle of doping process. Similarly, n-type semiconductors are doped with small impurities, typically phosphorous, that result in a surplus of free electrons. A solar cell is constructed by joining these two semiconductors in a "p-n junction".

Producing an electric field. The photovoltaic effect is enacted when sunlight, comprised of positively charged photons, these can be absorbed by the solar cell, transferring energy to the electrons that the become part of a current in an electrical circuit. In addition to the semiconductors, a solar cell consists of a transparent

encapsulate to prevent weathering, an anti-reflective layer, and a constant surface to transfer the electric current to the load.

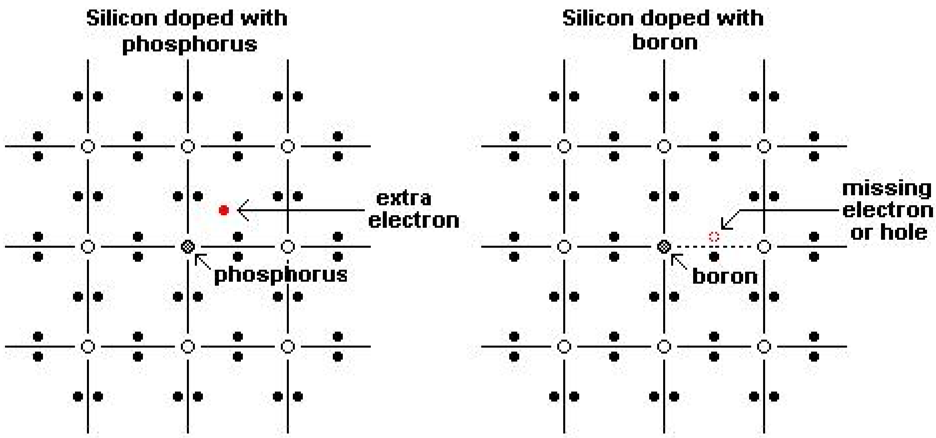

Figure 3.3 p-n junction semiconductors, (Jaber, 2007).

3.4 Types of photo voltaic cells:

There are basically three categories of photovoltaic systems with several types in each category.

3.5.1 Crystalline silicon PV systems:

Crystalline PV systems include two main types which they are: mono crystalline and polycrystalline silicon. They are grown from molten silicon and later they sliced into individual "cells". Then, they are sandwiched between glass plates and framed with aluminum to form a rigid plane.

A- Monocrystalline photovoltaic:

Considered to be the oldest and the most expensive production technique, on the other hand, it is also considered the most efficient sunlight conversion technology commercially available. It is efficiency ranges from 10-18%. Boules of pure single-crystal silicon are grown in an oven, then sliced into wafers, doped and assembled.

Figure 3.4 shows a solar cell made from monocrystalline silicon wafer.

Figure 3.4 a solar cell made from monocrystalline silicon wafer, (Eid, 2007).

B- Polycrystalline photovoltaic:

Often called Multi-crystalline, solar panels made with Polycrystalline cells are a little less expensive & slightly less efficient than Monocrystalline cells because the cells are not grown in single crystals but in a large block of many crystals. This is what gives them that striking shattered glass appearance. Like Monocrystalline cells, they are also then sliced into wafers to produce the individual cells that make up the solar panel, its efficiency ranges from7-12%, and figure 3.5 shows a solar cell made from polycrystalline silicon wafer.

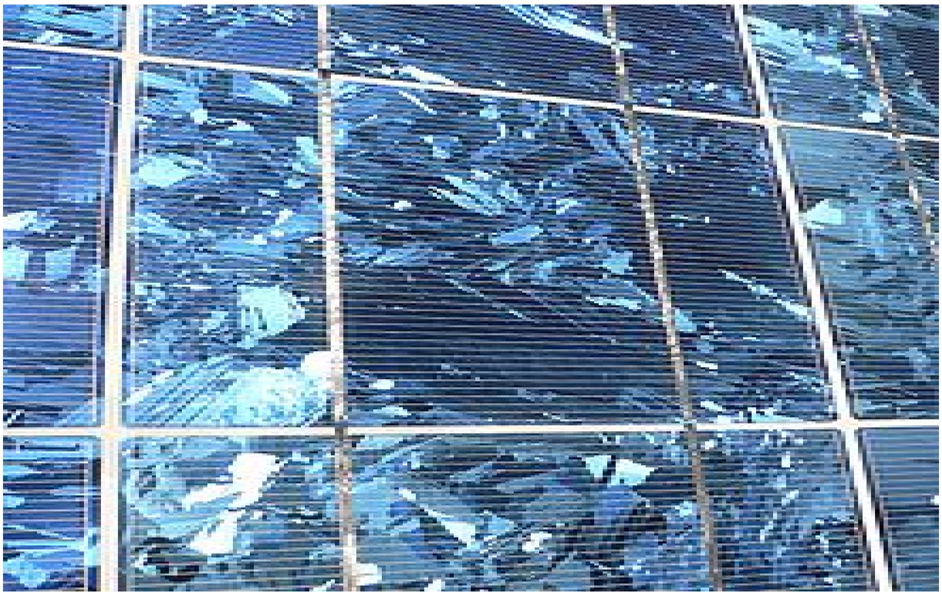

Figure 3.5 a solar cell made from polycrystalline silicon wafer, (Eid, 2007)

3.4.2 Ribbon silicon:

Ribbon-type photovoltaic cells are made by growing a ribbon from the molten silicon instead of an ingot. These cells operate the same as single and polycrystal cells. The anti-reflective coating used on most ribbon silicon cells gives them a prismatic rainbow appearance. Figure 3.6 shows a solar cells made a solar cell made from ribbon silicon wafer.

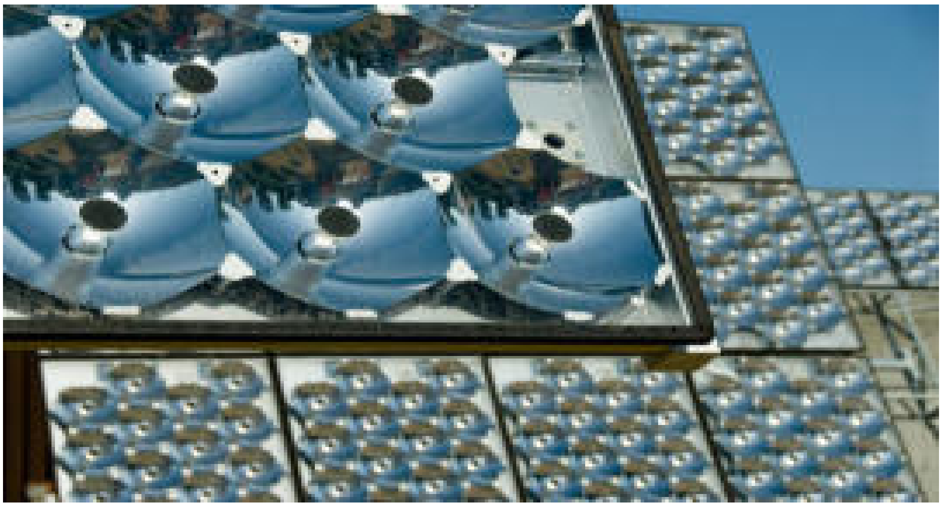

Figure 3.6 Ribbon silicon cells, (Eid, 2007)

3.4.3 Amorphous photovoltaic:

Also called "flexible photovoltaic systems", it's produced in vacuum plasma ovens which deposit a thin layer of silicon material into a flexible polymer or steel substrate. One of the most important advantages of this type is that its lightweight and flexible properties facilitate the integration of the cells into traditional buildings product and systems such as roofs, windows or facades. Its efficiency ranges between 5-7%. Figure 3.7 shows a solar cell made from amorphous silicon cells.

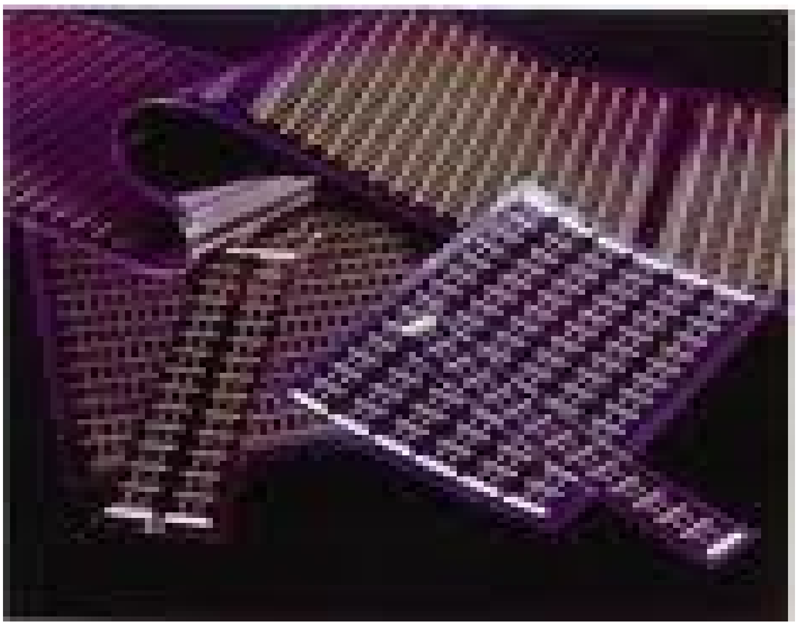

Figure 3.7 Amorphous silicon cells, (Eid, 2007).

3.5 Solar energy in Jordan:

In Jordan the average insulation intensity on a horizontal surface is approximately 5–7 kWh/ m^2/d, which is one of the highest in the world (Mohsen and Jaber, 2001).

The solar water heating industry in the country is well developed. By 1999, about 25% of homes (i.e., 2.3×10^5 homes) had been fitted with solar water heaters, thereby avoiding the need for approximately 2% of the total oil imports, with an associated savings of about US$12 million annually, depending on crude oil price, (Mohsen and Jaber, 2001).

Solar energy is employed to evaporate ~$90\times10^6 m^3$ annually of Dead Sea water in the process of potash and other salts production, thereby avoiding approximately 4×10^6 tons of fuel oil having to be imported annually. Photovoltaic systems are employed in some remote regions for water pumping systems, powering radio and telephone stations, as well as supplying electrical energy for clinics, schools, and a few small villages. Other applications of solar energy such as passive heating and cooling of buildings and food drying are under consideration. (Mohsen and Jaber, 2001).

Chapter Four

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Wind Energy

Chapter Four

Wind Energy

4. Introduction

Wind energy, as a major part of renewable energy is an abundant resource that produces energy at relatively low cost, with virtually no emissions. Therefore, it is likely to be an important component of future power generation schemes.

The vast majority of wind power development to date has occurred in developed rather than in the developing countries. Some developing countries such as India and China are rapidly increasing their wind capacity, but in the poor countries there is a marked absence of utility-scale wind power development. Wind energy is rapidly developing into a mainstream power source in many countries of the world, with over 70000MW of installed capacity worldwide and an average annual market growth rate of 28%. Wind energy would provide as much as 29% of the worlds electricity needs by 2030. (Aldohni, 2009).

4.1 History of wind energy:

The wind has been playing along and important role in the history of human civilization. The first known use of wind dates back 5000 years in Egypt, where boats used sails to travel from shore to shore. The first true windmill, a machine with vanes attached to an axis to produce circular motion, may have been built as early as 2000 B.C. in ancient Babylon. By the 10th century A.D., windmills with wind-catching surfaces as long as 16 feet and as high as 30 feet were grinding grain in the area now known as eastern Iran and Afghanistan, (Aldohni, 2009).

The western world discovered the windmill much later. The earliest written references to working wind machines date from the 12th century. These too were used for milling

grain. It was not until a few hundred years later that windmills were modified to pump water and reclaim much of Holland from the sea**,** (Aldohni, 2009).

The familiar multi-vane "farm windmill" of the American Midwest and West was invented in the United States during the latter half of the l9th century. In 1889 there were 77 windmill factories in the United States, and by the turn of the century, windmills had become a major American export. Until the diesel engine came along, many transcontinental rail routes in the U.S. depended on large multi-vane windmills to pump water for steam locomotives. Farm windmills are still being produced and used, though in reduced numbers, and show no sign of becoming obsolete. They are best suited for pumping ground water in small quantities to livestock water tanks. Without the water supplied by the multi-vane windmill, beef production over large areas of the West would not be possible. In the 1930s and 1940s, hundreds of thousands of electricity producing wind turbines were built in the U.S. They had two or three thin blades which rotated at high speeds to drive electrical generators. These wind turbines provided electricity to farms beyond the reach of power lines and were typically used to charge storage batteries, operate radio receivers and power a light bulb or two, (URL: http//:www.example essay.com).

4.2 Background of wind energy:

The kinetic energy in the wind is a promising source of renewable energy with significant potential in many parts of the world. The energy that can be captured by wind turbines is highly dependent on the local average wind speed. Regions that normally present the most attractive potential are located near coasts, inland areas with open terrain or on the edge of bodies of water. Some mountainous areas also have good potential. In spite of these geographical limitations for wind energy project siting, there

is ample terrain in most areas of the world to provide a significant portion of the local electricity needs with wind energy projects, (RETScreen).

Figure 4.1 wind mill farm, (RETScreen).

The world-wide demand for wind turbines has been growing rapidly over the last 15 years. During 2001 alone the wind energy industry installed close to 5,500 MW of new generating capacity. More than 24,000 MW of wind energy capacity is estimated to be in operation around the world (Wind Power Monthly, 2001). Much of this demand has been driven by the need for electric power plants that use “cleaner fuels.” Wind farms that use multiple turbines are being constructed in the multi-megawatt range, as depicted in Figure 4.1. In the last decade, typical individual turbine sizes have increased from around 100 kW to 1 MW or more of electricity generation capacity, with some wind energy projects now even being developed offshore, as shown in Figure 4.2. The result of all this progress is that, in some areas of the world, large-scale wind energy projects now generate electricity at costs competitive with conventional power plants.

figure 4.2 offshore wind turbine farm, (RETScreen).

4.3 Description of wind turbines:

A wind turbine consists of a rotor or blades which converts the wind's energy into mechanical energy (turbine). The energy that moves the wind ("kinetic energy") moves the blades. They (blades) spin a shaft that leads from the hub of the rotor to a generator. The generator turns that rotational energy into electricity which is then stored in batteries or transferred to home power grids or utility companies for use in the usual way. If you place an object like a rotor blade in the path of that wind, the wind will push on it, transferring some of its own energy of motion to the blade. This is how a wind turbine captures energy from the wind. At its essence, generating electricity from the wind is all about transferring energy from one medium to another.

How wind turbines work have to do with the size and shape of the rotors, the location of the turbine, height of the blades. Two or three bladed turbines are most popular

nowadays because of more thrust and less wind resistance. Wind turbines can be made cheaper if more people opt for it. Mass production in case of wind energy will bring down the material and installation cost, which today is not possible for average consumer who needs cheap electricity.

4.4 Wind turbine sizes.

Wind turbines are available in a variety of sizes, and therefore power ratings. The largest machine has blades that span more than the length of a football field, stands 20 building stories high, and produces enough electricity to power 1,400 homes. A small home-sized wind machine has rotors between 3 and 10 meters in diameter and stands upwards of 10 meters and can supply the power needs of an all-electric home or small business. The wind turbines may be categorized into four main types according to their sizes, as shown in table 4.1.

Table 4.1 the main categories of wind turbines, (Aldohni, 2009).

Size of wind turbine	Power rating (KW)
Micro turbines	Less than 1 kilowatt
Small turbines	10-100 kilowatt
Medium-sized turbines	100-1000 kilowatt
Large turbines	More than 1000 kilowatt
Huge turbines	Up to 4 megawatt

4.5 Wind energy: current status and future:

The global installed capacity of wind energy has been expanding faster than any other source of renewable energy. From just 74750 MW in 1997 the world total has multiplied to reach over 93849 MW at the end of 2007. (WWEA, 2008)

In the year 2007 alone, 19696 MW of new wind energy capacity were added compared with the year 2006 when only 15120 MW were added, summing up to a global installed capacity of 93849 MW by the end of December 2007. The added capacity equals a growth rate of 26.6% compared with 25.6% in 2006. The currently installed wind power capacity generates 200,000 GWh per year, equaling 1.3% of the global electricity consumption, (WWEA, 2008).

Table 4.2 shows the first 20 countries of the world that have the largest installed capacity at the end of 2007. According to this classification Jordan ranked 62nd out of 74 countries in the year 2007; on the other hand it was ranked 60th in year 2006, (WWEA, 2008).

Europe decreased its share in installed capacity. However, Europe is still the strongest continent whilst North America and Asia are increasing rapidly their shares. In 2007, wind capacity grew more in Europe than in any other power generating technology, an increase is driven by Spain. The installed capacity of wind energy in Europe increased by 18% last year, to reach a level of 56.54 GW (WWEA, 2008).

Table 4.2 Top 20 countries listed according to their installed capacity at end of 2007 (WWEA, 2008).

Ranking total 2007	country	total installed capacity end 2007 (MW)	total installed capacity end 2006 (MW)	rate of growth 2007(%)
1	Germany	22,247	20,622	7.9
2	USA	16,819	11,603	45
3	Spain	15,145	11,630	30.2
4	India	7,850	6,270	25.2
5	china	5,899	2,599	127
6	Denmark	3,125	3,136	-0.4
7	Italy	2,726	2,123	28.4
8	France	2,455	1,567	56.7
9	UK	2,389	1,961	21.8
10	Portugal	2,130	1,716	24.1
11	Canada	1,846	1,460	26.4
12	Netherlands	1,747	1,559	12.1
13	Japan	1,583	1,309	17.5
14	Austria	982	965	1.8
15	Greece	873	758	15.3
16	Australia	817	817	0.0
17	Ireland	805	746	7.9
18	Sweden	789	571	38.1
19	Norway	333	325	2.5
20	new Zealand	322	171	88.3

4.6 Wind energy in Jordan.

Jordan possesses high potential of wind energy resources where the annual average wind speed exceeds 7 m/s (at 10 m height) in some areas of the country. The long term climatic data are available at the Jordan Meteorological Department (JMD). Some other institutions like the Ministry of Energy and Mineral Resources (MEMR) and the Royal Scientific Society (RSS) have some measurements of such data especially wind and solar data for the purpose of assessing the potential of these resources for power generation and other applications in Jordan.

In 1988, the MEMR, JMD and other local institutions by co-operation with RISO National Laboratory in Denmark, conducted the Wind Atlas for Jordan. This Atlas was the first of its kind in the region and is considered as a reference for determining and selecting the areas that have promising potential for electricity generation in Jordan.

The Wind Atlas indicated out two windy regions in the northern and southern parts of Jordan. The estimated potential for wind power generation in these regions is about 50 MW (25 MW in the north and 25 MW in the south) without major changes in the grid and power system, and this potential could amount due to variations of wind speeds to 65–145 GWh per year, which corresponds to 1.5–2.5 % of the total electric energy generated in the country in the year 1997, (Sabra, 1999).

The preliminary results of the wind measurements at several locations in the country are quite promising for power generation. The diversity of Jordan's topography (400 m below sea level at the Dead Sea and up to 1700 m above sea level at the northern and southern parts of the country), as well as the distribution of the electric grid all over the country especially through the windy areas, present good conditions for the utilizations of wind energy for power generation.

Chapter Five

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The Mathematical Model and Data Preparation

Chapter Five

The Mathematical Model and Data Preparation

5. Introduction

In this chapter, mathematical equations representing the model and the data required as program input are stated and collected in tables and figures. This was carried out for all selected sites which were:

- Amman.
- Aqaba.
- Alkarak.
- Dead Sea.
- Ajloun.
- Irbid.

5.1 Mathematical model of Off-grid photo voltaic unit:

Off grid PV unit represents a stand alone system with or without generation set. Figure (5.1) shows the principle of work of the off-grid PV system.

The produced energy from the PV array is either fed directly to the DC load or it will be stored in the batteries before having it delivered to the load, either DC or AC.

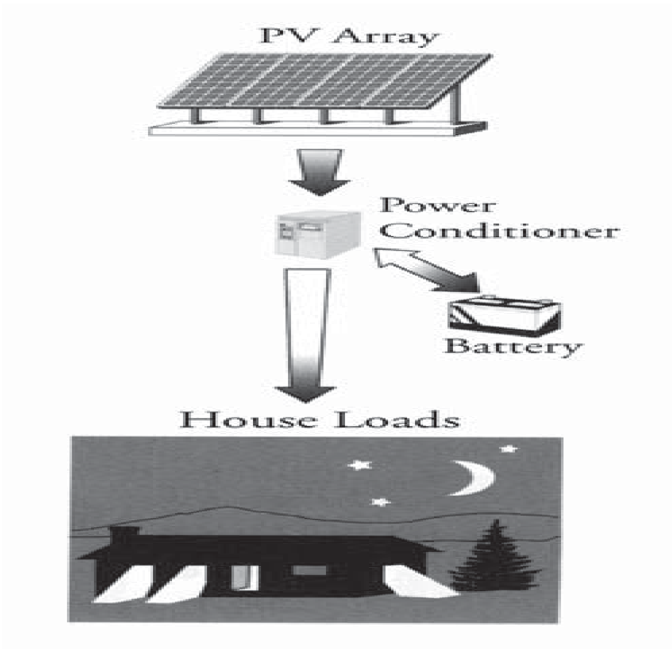

Figure 5.1 Stand-Alone Off-Grid PV System Schematic, (RETScreen)

Following are the equations and quantities that represent the mathematical model:

5.1.1 Solar radiation:

Solar radiation is the energy given off by the sun in all directions. When this energy reaches the earth's surface, it is called insolation.

Solar radiation gives out light and heat to the earth in the form of electromagnetic waves. It has different wave lengths. Radiation such as ultra violet radiation, X rays and visible light has short wave lengths. Infrared radiation has a long wave length.

The atmosphere affects the amount of solar radiation received. When solar radiation travels through the atmosphere, some of it is absorbed by the atmosphere (16%). Some of it is scattered to outer space (6%). Some of it is reflected by clouds (28%). About 47% of it reaches the earth's surface, (Acosta, 2009).

The following equations used to calculate both horizontal and vertical solar radiation:

1- Horizontal solar radiation:

The extraterrestrial horizontal solar radiation quantity, H_o represents the solar radiation falling on a horizontal plane of m^2 area outside earth atmosphere and equal:

$$Ho = Io * \sin(\alpha) \qquad (5.1)$$

Where:

I_o is the solar constant which is equal to 1367 w/m^2

α is the solar altitude angle.

2- Vertical solar radiation:

The extraterrestrial vertical solar radiation quantity, V_o represents the solar radiation falling on a vertical plane of m^2 area outside earth atmosphere and equal:

$$Vo = Io \cos(\alpha) \cos(\omega) \qquad (5.2)$$

Where: ω is the hour angle.

5.1.2 Declination angle:

The declination angle is the angular position of the sun at solar noon, with respect to the plane of the equator. Its value in degrees is given by Cooper's equation:

$$\beta = 23.45 \sin\left(2\pi \frac{284+n}{365}\right) \qquad (5.3)$$

Where n is the day of year (i.e. n =1 for January 1, n = 32 for February 1, etc.). Declination angle varies between -23.45° on December 21 and +23.45° on June 21 for the northern hemisphere.

Solar altitude angle, $\alpha = \sin^{-1}(\sin\beta \ \sin ø + \cos\beta \cos ø \cos\omega)$ ……….(5.4)

Where, ø is the latitude of the position on earth surface.

5.1.3 Energy collection:

Energy falling on a tilted plane of area 1.0 m^2 and angle β, out side earth atmosphere is:

$E_o = H_o \cos(\beta) + V_o \sin(\beta) = I_o [\sin(\alpha) \cos(\beta) + \cos(\alpha) \cos(\omega) \sin(\beta)]$ ….(5.5)

5.1.4 The energy delivered by the PV array:

$E_d = A\, \eta_{Pv}\, I\, [\sin(\alpha) \cos(\beta) + \cos(\alpha) \cos(\omega) \sin(\beta)]$ ………………………(5.6)

Where:

A: is the area of the array.

η_P: is the efficiency of the PV cell.

I: is the solar radiation on ground surface = Io (Kt).

Where:

Kt is the clearness index which equals approximately 0.8 in Jordan.

5.1.5 Available energy of the array:

Energy available for domestic use at out put of the array, Ea is:

$E_a = E_d * \eta_{ch} * \eta_{batt} * \eta_{inv} * \eta_{conn}$ ....(5.7)

Where:

E_d : is the energy delivered by the PV array.

η_{ch} : is the efficiency of the charger.

η_{batt} : is the efficiency of the battery.

η_{inv} : is the efficiency of the inverter.

η_{conn} : is the efficiency of the connection.

Figure 5.2 shows a description of solar angles.

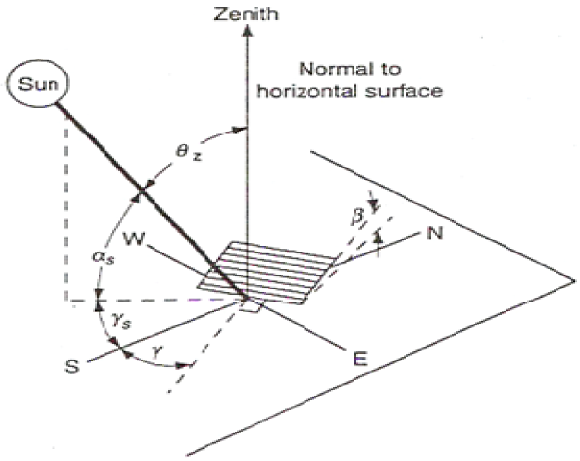

Figure 5.2.description of solar angles.

5.2 Load calculation of domestic use:

A typical Jordanian house with approximately area equal 150 to 160 m^2 was taken as an example for all selected sites to calculate the approximated consumption of electricity.

Four cases of calculations were carried out; the first two cases represented the daily consumption in summer season while the others represented the daily consumption in winter season.

Tables 5.1, 5.2, 5.3, and 5.4 show the daily consumption of electricity.

Table 5.1 First design load of expected electricity consumption for summer season

Appliance	Qty		approximate wattage		Hrs per day	Expected wh/day
Television	1	×	70	×	5	350
Lights	6	×	50	×	6 ×0.5	900
Refrigerator /freezer	1	×	70	×	24×0.6	1008
Microwave	1	×	600	×	1	600
Computer	1	×	80	×	4	320
Shaver	1	×	16	×	0.25	4
Washing machine	1	×	1700	×	2	3400
Approximately total = 6.6 kWh/day						

Table 5.2 Second design load of expected electricity consumption for summer season

Appliance	Qty		approximate wattage		Hrs/day	Expected Wh/day
Television	1	×	70	×	5	350
Lights	6	×	50	×	6×0.5	900
Refrigerator /freezer	1	×	70	×	24×0.6	1008
Microwave	1	×	600	×	1	600
Heater /Air conditioner	1	×	1350	×	1	1350
Blender	1	×	150	×	0.25	37.5
Washing machine	1	×	1700	×	2	3400
Approximately total = 7.6 kWh/day						

Table 5.3 First design load of expected electricity consumption for winter season

Appliance	Qty		Avg. wattage		Hrs per day	Avg. watt Hrs/day
Television	1	×	70	×	5	350
Lights	6	×	50	×	6×0.5	900
Washing machine	1	×	1700	×	2	3400
Refrigerator /freezer	1	×	70	×	24×0.6	1008
Microwave	1	×	600	×	1	600
Computer	1	×	80	×	4	320
Shaver	1	×	16	×	0.25	4
Vacuum cleaner	1	×	300	×	1	300
Hair dryer	1	×	1000	×	0.5	1000
Approximately total = 7.9 kWh/day						

Table 5.4. Second design load of expected electricity consumption for winter season

Appliance	Qty		Avg. wattage		Hrs per day	Avg. watt Hrs/day
Television	1	×	70	×	5	350
Lights	6	×	50	×	6×0.5	900
Iron	1	×	1200	×	3	3600
Refrigerator /freezer	1	×	70	×	24×0.6	1008
Heater /Air conditioner	1	×	1350	×	2	2700
Blender	1	×	150	×	0.25	37.5
Shaver	1	×	16	×	0.25	4
Approximately total = 8.6 kWh/day						

From the previous tables, one can note that the worst conditions which must be considered as design conditions are the fourth table of winter season represents the maximum possible consumption of electricity which is 8.6 kWh/day. This assumed of 9 kWh/day will be supplied as daily requirements available energy of the systems follows: 15% from the wind energy output and 85% from the solar array output. In case of spots of non Applicable wind velocities, then 100% will be supplied by the solar array.

5.3 Load at non sunny days:

Calculations of non sunny days:

It was necessary to decrease energy use in such days to 4 kWh as shown in table (5.5).

Table (5.5): Minimum electricity consumption for non sunny day.

Appliance	Qty		Avg. wattage		Hrs per day	Avg. watt Hrs/day
Television	1	×	70	×	5	350
lights	4	×	50	×	6×0.5	600
Refrigerator /freezer	1	×	70	×	24×0.6	1008
Heater /Air conditioner	1	×	1350	×	1.5	2700
Approximately total= 4 kWh/day						

The following are the specifications of the batteries:

Type	OPzS Solar 550
Nominal Voltage (V)	2V
Nominal Capacity C120 - 1.85V/C - 25°C (Ah)	550 Ah
Length (mm)	126 mm
Width (mm)	208 mm
Short Circuit current	3250 A
discharge depth	80%

5.4 Solar radiation input values:

Solar radiation as one of the program inputs was calculated, both vertical and horizontal component were calculated and the total solar radiation also was calculated in order to find the supplied power by PV cells.

Since that the solar radiation depends on the latitudes and longitude of each site, Table 5.5 shows the latitude and longitude of the selected sites.

Table 5.6 latitude and longitude of the selected locations.

site name	Latitude(ϕ)	Longitude	approximated Altitude(m)
Amman	31.8°	36°	759
Aqaba	29°	35°	254
Irbid	32.3°	35°	650
Alkarak	31.7°	35°	950
Dead sea	31°	35°	-380
Ajloun	32°	35°	1000

5.4.1 Solar Time

Solar time based on the apparent angular motion of the sun across the sky, with solar noon the time the sun crosses the meridian of the observer.

Following are the typical steps which they were followed to calculate the solar time of the Aqaba sites at 23rd of Jun:

B= (n-1)*360 /365……………………………………………………………….(5.8)

Where n is the day of the year.

B= (23-1) * 360 / 365 = 21.7

ST= 229.2(0.000075+0.001866 cos B – 0.032077 sin B – 0.014615 cos 2B – 0.04089 sin 2B)

Where ST is the standard time,

ST= 229.2 (0.000075 + 0.001866 cos (21.7) – 0.032077 sin(21.7) – 0.014615 cos(43.4) – 0.04089 sin (43.4)) = - 11.17

Solar time – standard time = -4 (Lloc – Llon) +ST

Where:

Lloc: is the local standard meridian

Llon: is the local longitude

Solar time -8:00:00 = -4 (29-35) – 11.17= 12.84

Table 5.7 shows the results of B, ST, and solar time in minutes of all sites during the year.

Table 5.7 Calculated values of B, E, and solar time of all sites for all year months.

Month	B	E	solar time – standard time (minutes)					
			Ajloun	Amman	Alkarak	Aqaba	Irbid	Dead Sea
January	21.7	-11.17	-0.37	6.03	1.63	12.83	0.83	4.83
February	44.3	-14.2	-3.4	3	-1.4	9.8	-2.2	1.8
March	74	-9.06	1.74	8.14	3.74	14.94	2.94	6.94
April	102.6	-0.24	10.56	16.96	12.56	23.76	11.76	15.76
May	132.1	3.94	14.74	21.14	16.74	27.94	15.94	19.94
June	162.7	0.004	10.8	17.2	12.804	24.004	12.004	16.004
July	177.5	-3.23	7.57	13.97	9.57	20.77	8.77	12.77
August	222	-5.07	5.73	12.13	7.73	18.93	6.93	10.93
September	251.5	3.84	14.64	21.04	16.64	27.84	15.84	19.84
October	281	13.89	24.69	31.09	26.69	37.89	25.89	29.89
November	305.7	16.19	26.99	33.39	28.99	40.19	28.19	32.19
December	336	8.19	18.99	25.39	20.99	32.19	20.19	24.19

5.5 The inverter power:

P_{inv} = K * P total/5 …………………………………………….(5.9)

5.6 Wind energy power:

5.6.1 Mathematical model of the off-grid wind turbines unit:

There are several density functions which can be used to describe the wind speed frequency curve. The two most common ones are the Weibull and the other is Rayleigh functions. From the statistically point of view, the Weibull is a special case of the Pearson type III or generalized gamma distribution, while the Rayleigh (or the chi with two degrees of freedom (chi-2)) distribution is a subset of the Weibull distribution. The Weibull method is a two-parameter distribution, while the Rayleigh has only one parameter. This makes the Weibull distribution more versatile and the Rayleigh somewhat simpler to use. (Aldohni, 2009)

The wind speed (v) is distributed as the Weibull distribution if its probability density function is:

$$P(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{K-1} \exp\left(-\left(\frac{v}{c}\right)^{K}\right) \quad \text{where: } (k > 0,\ v > 0,\ c > 1) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.5)$$

Where c is the scale factor, k is the shape factor, specified by the user; this is typically range from 1 to 3. For a given average wind speed, a lower shape factor indicates a relatively wide distribution of wind speeds around the average while a higher shape factor indicates a relatively narrow distribution of wind speeds around the average. A lower shape factor will normally lead to a higher energy production for a given average wind speed. The scale factor, c, can be calculated from the following equation:

$$c = \frac{\overline{v}}{\Gamma\left(1 + \frac{1}{k}\right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.6)$$

Where $\overline{v}$ is the average wind speed value and Γ is the gamma function. (El-wakil, 1984)

Also, there is another way can be used to find the values of k and c. for k the values is above 1.5 and less than 3 (or 4). However the ratio c/v is essentially a constant, with value of about 1.12. This means that the scale parameter is directly proportional to the mean wind speed for this range of k.

$c = 1.12\ V, \quad (1.5 \leq k \leq 3.0)$……………………………………………..…(5.7)

Most good wind regimes will have the shape parameter k in this range so this estimate of (c) in term of (v) will have wide applications.

The following equation will be used to examine the value of (k). (El-wakil, 1984)

$k = 1.09 + 0.2\ (v)$…………………………………………………..……. (5.8)

In some cases, the model will calculate the wind speed distribution from the wind power density at the site rather than from the wind speed. The relations between the wind power density *WPD* and the average wind speed *v* are:

$WPD = \Sigma 0.5 * \rho * A * v^3 * p(v)$ ……………………………………..... (5.7)

since that the density of air equals to 1.22 kg/m^3, so:

$$WPD = 0.61 * A * \sum_{V_{in}}^{V_{out}} v^3 * p(v)$$

Where ρ is the air density and p (v) is the probability to have a wind speed v during the year, (RETScreen).

So, the power equation for wind potential energy defined as:

$P = \frac{١}{٢} \rho A v^3$ ………………………………………………… ……..……..(5.16)

5.6.2 Collection of data:

The main data that was collected from the metrological department (MD) are:

- Minimum and maximum temperatures (°C).
- Daily sunshine hours (h).

Many calculations were carried out, and all of these calculations and discussion of results described in the following sections.

5.6.3 Wind speed data of the sites:

Wind speeds for all selected sites were collected from the Jordanian metrological department (JMD). The collected data was monthly average velocity for all selected sites; In addition, the average daily wind speed for all sites of January and July months was collected.

Figures 5.3, 5.4 show the distribution of average wind speed of all selected sites for both January and July months, respectively.

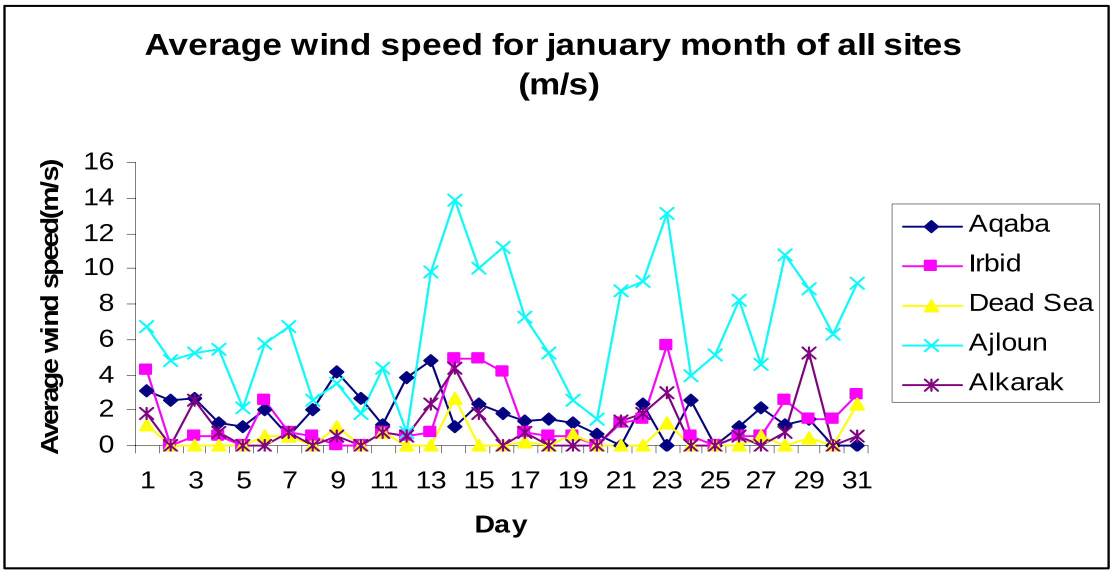

Figure 5.3. Wind speed of January month for all selected sites.

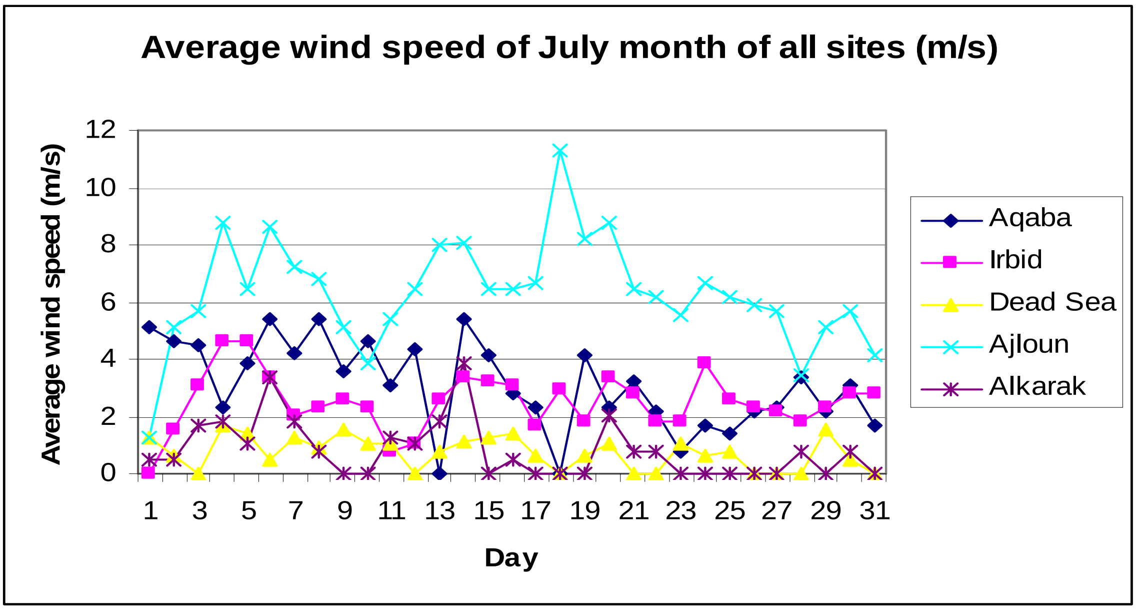

Figure 5.4. Wind speed of July month for all selected sites.

Figure 5.4 indicates that Alkarak, Ajloun and Irbid seem to be the promising sites for wind energy.

5.6.4 The percentage of wind turbine supply.

At first, the specifications of selected turbine are described here to use them in the following calculations.

- Specifications of the used turbine:

Rated Power	1 kW
Maximum Output Power	1.2 kW
Output Voltage	48 V
Blade Quantity	3 Fiber Glass Blades
Generator	Three Phase Permanent Magnetic Generator
Generator Efficiency	>0.85
Turbine Weight	60 kg
Noise	28 db(A)
Temperature Range	-20°C to +50°C
Design Lifetime	30 Years
Warranty	Standard 5 Years Extended 10 Years

5.6.5 Calculations of Weibull distribution parameters.

It was assumed to be supplied 15 % by the wind turbine which equals to:

9000 Wh/day * 0.15 = 1350 Wh/day (the percentage of wind energy). in order to calculate the generated power of wind turbine of all sites, The curve of Weibull distribution was assumed to be linear, so the shape was assumed to be a triangle and its area represents the generated power which is equals to 0.5 * (average speed – cut in speed of the used wind turbine) * rated power.

Table 5.8 shows the average wind speed of all selected sites during the year, whereas figure 5.5 shows wind speed distribution of all sites during the months of the year.

Table 5.8 the average wind speed of all selected sites during the year (m/s).

Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average Speed	k	c
Aqaba	3.73	4.21	5.37	6.14	6.29	6.58	5.79	6.45	7.18	5.53	4.28	3.81	5.44	2.18	6.1
Ajloun	8.64	8.94	7.62	6.85	6.50	6.70	6.30	6.52	6.55	6.93	6.43	7.12	7.09	2.5	7.94
Irbid	6.35	6.57	6.57	6.54	5.89	7.59	8.43	7.23	5.46	6.71	5.31	6.73	6.61	2.41	7.4
Amman	3.27	3.8	3.75	3.62	3.61	4.06	4.22	3.43	2.56	2.09	2.55	2.65	3.3	1.75	3.69
Alkarak	9.69	8.23	8.69	8.08	6.82	7.16	6.79	6.60	5.28	4.86	7.86	8.38	7.37	2.56	8.25
Dead Sea	1.21	0.96	1.37	1.75	2.58	2.25	1.80	1.76	1.70	0.70	0.71	1.07	1.49	1.39	1.67

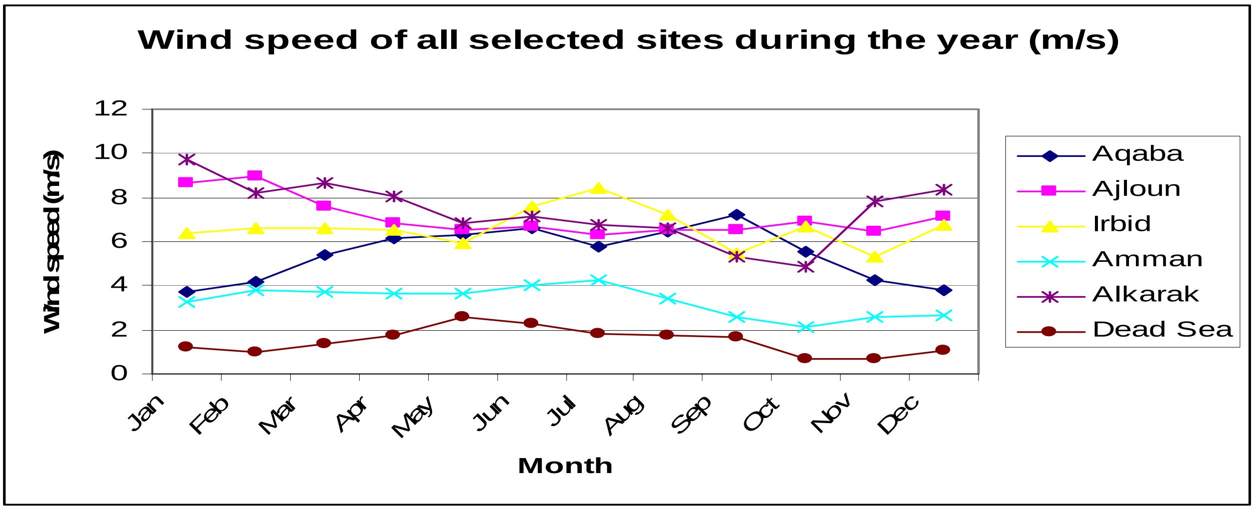

Figure 5.5 Distribution of the wind speed of all selected sites during the year.

The following is a typical calculation for one site single time:

Alkarak:

$$P\ (\text{v-cut in}) = \frac{2.56}{8.25}\left(\frac{2.5}{8.25}\right)^{1.56}\exp\left(-\left(\frac{2.5}{8.25}\right)^{2.56}\right)$$

$$= 0.15$$

$$P\ (\text{v-maximum}) = \frac{2.56}{8.25}\left(\frac{9.69}{8.25}\right)^{1.56}\exp\left(-\left(\frac{9.69}{8.25}\right)^{2.56}\right)$$

$$= 0.39$$

P (v-cut in) – P(v-flat rate) = 0.39 – 0.15

= 0.24

No. hours per year = 0.24*8760 = 2102 hour/year

No. hours per day = 2102/365 = 5.75hour/day.

Output power = 0.5 * (Vmax – Vcin) * Rated power

= 0.5 * (9.69 – 2.5) *1000 = 3595 Wh/day

Chapter Six

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COMPUTER SIMULATION

Chapter six

Computer Simulation

6. Introduction:

This chapter contains description of the computer code and the flow chart.

6.1 Algorithm of the computer simulation program:

The second part of this study based on using the computer programming language in order to make all calculations which are related to the wind and/or solar energy fields easier.

In this study JAVA language programming was used and all previous calculations were carried out using the JAVA program.

JAVA programming language was used to build a computer simulation program to calculate the equations of the hybrid power systems (solar- wind).

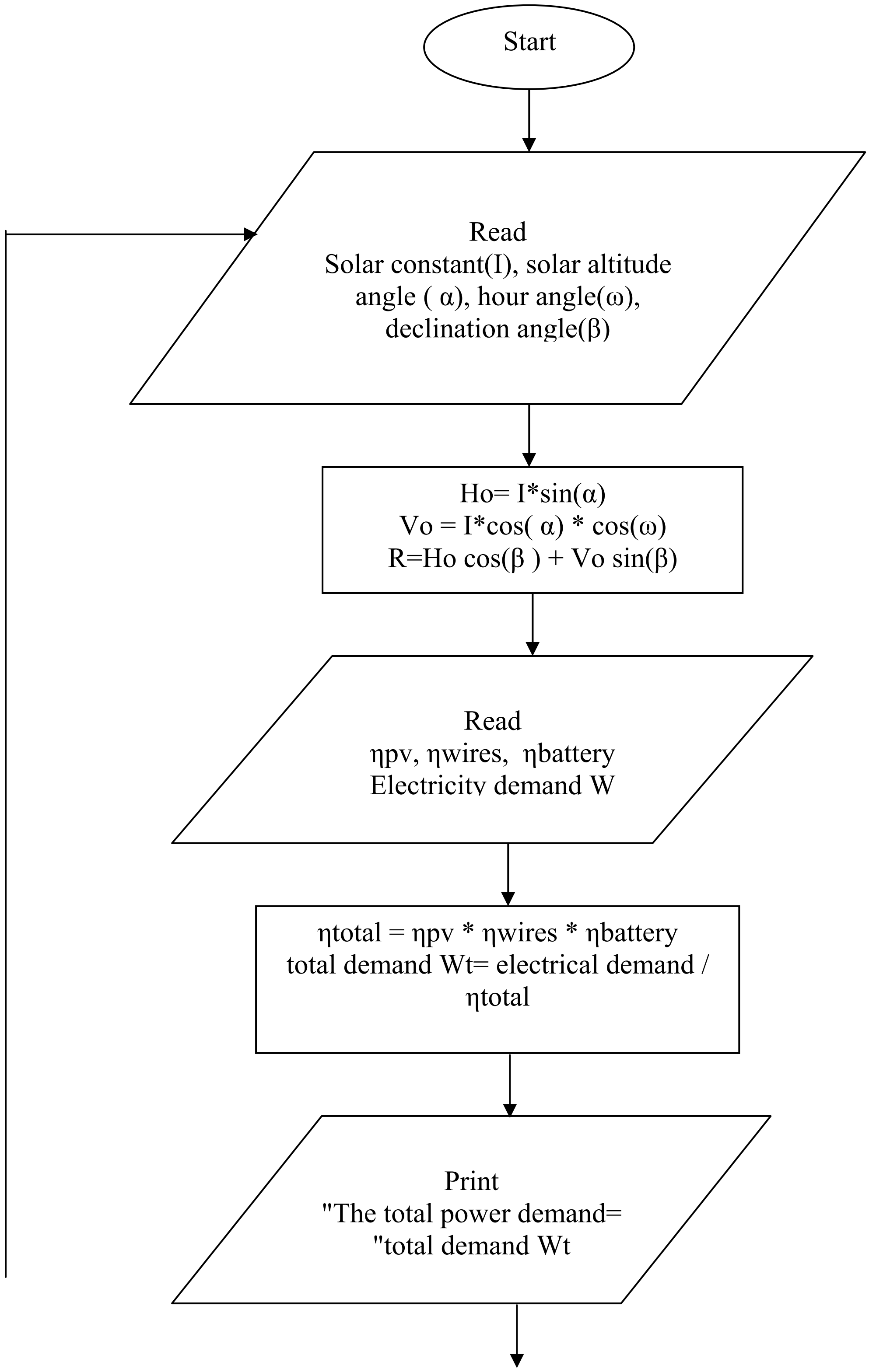
With respect to the solar energy the algorithm of the program depends on the main inputs which they were the efficiencies of the inverter, battery, charger, PV, and the connection, and finally the daily solar radiation of the site. If you have entered these values you will get the output power of $1m^2$ of PV cells. Then the daily consumption of electricity will be required to get the required area (m^2) of the PV cells.

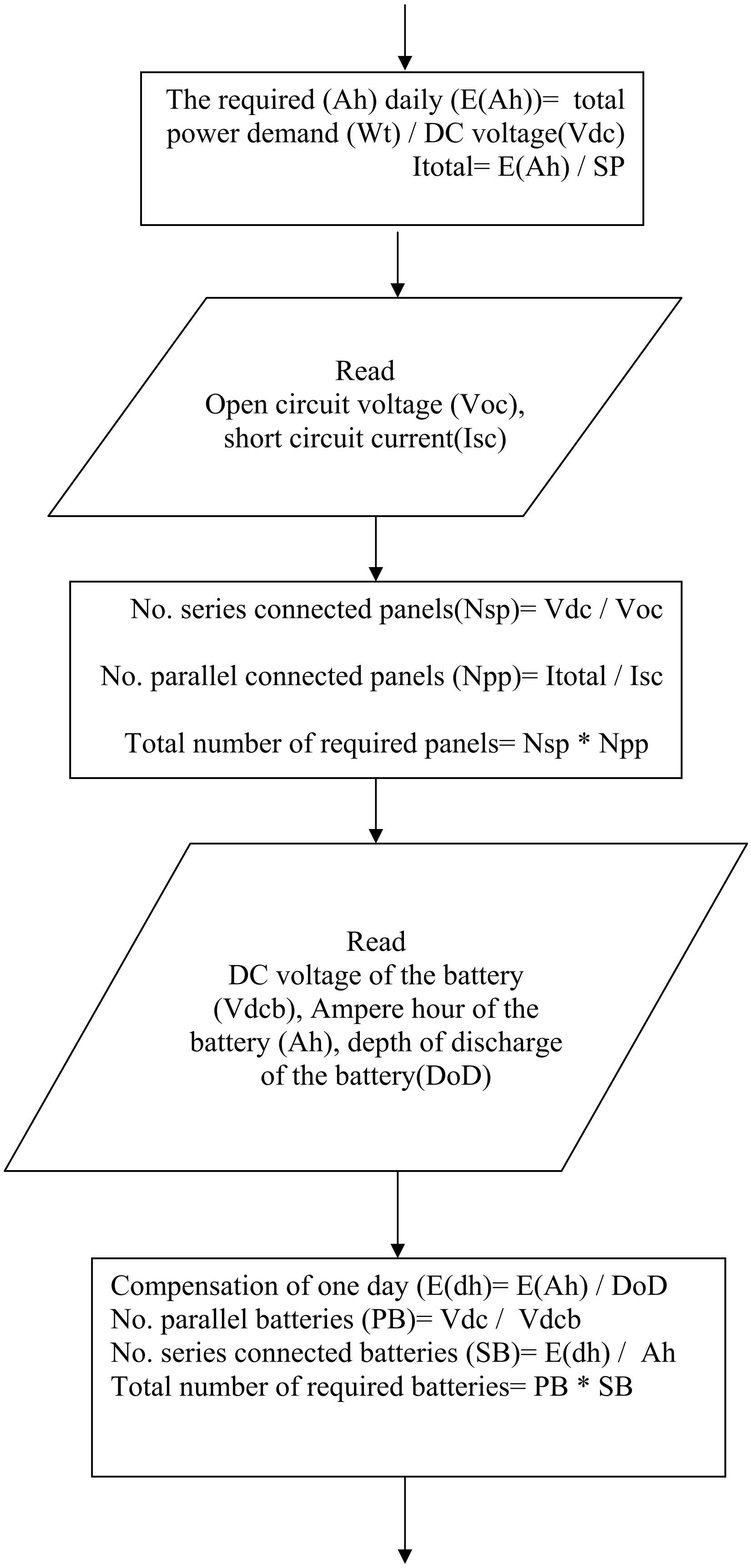
To calculate the number of required modules you should enter the area of the used type of the PV cells in m^2.

For wind energy, the program calculating the probability of both cut in speed, and the yearly average wind speed of the selected site by using equation 5.5, then the difference between these probabilities calculated to find the number of yearly probable hours also the daily probable hours. To calculate the approximated output the shape of weibull distribution will be assumed to be linear as mentioned in section 5.7.2 and it used the rule of triangle area to find the output power in watt.

All previous calculations were carried out using the computer program by entering the required inputs and get the required output also the results have been guaranteed by manually calculations.

Figure 6.1 describes the algorithm of Java code program.





The required (Ah) daily (E(Ah))= total power demand (Wt) / DC voltage(Vdc)
Itotal= E(Ah) / SP
Read
Open circuit voltage (Voc),
short circuit current(Isc)
No. series connected panels(Nsp)= Vdc / Voc
No. parallel connected panels (Npp)= Itotal / Isc
Total number of required panels= Nsp * Npp
Read
DC voltage of the battery (Vdcb), Ampere hour of the battery (Ah), depth of discharge of the battery(DoD)
Compensation of one day (E(dh)= E(Ah) / DoD
No. parallel batteries (PB)= Vdc / Vdcb
No. series connected batteries (SB)= E(dh) / Ah
Total number of required batteries= PB * SB

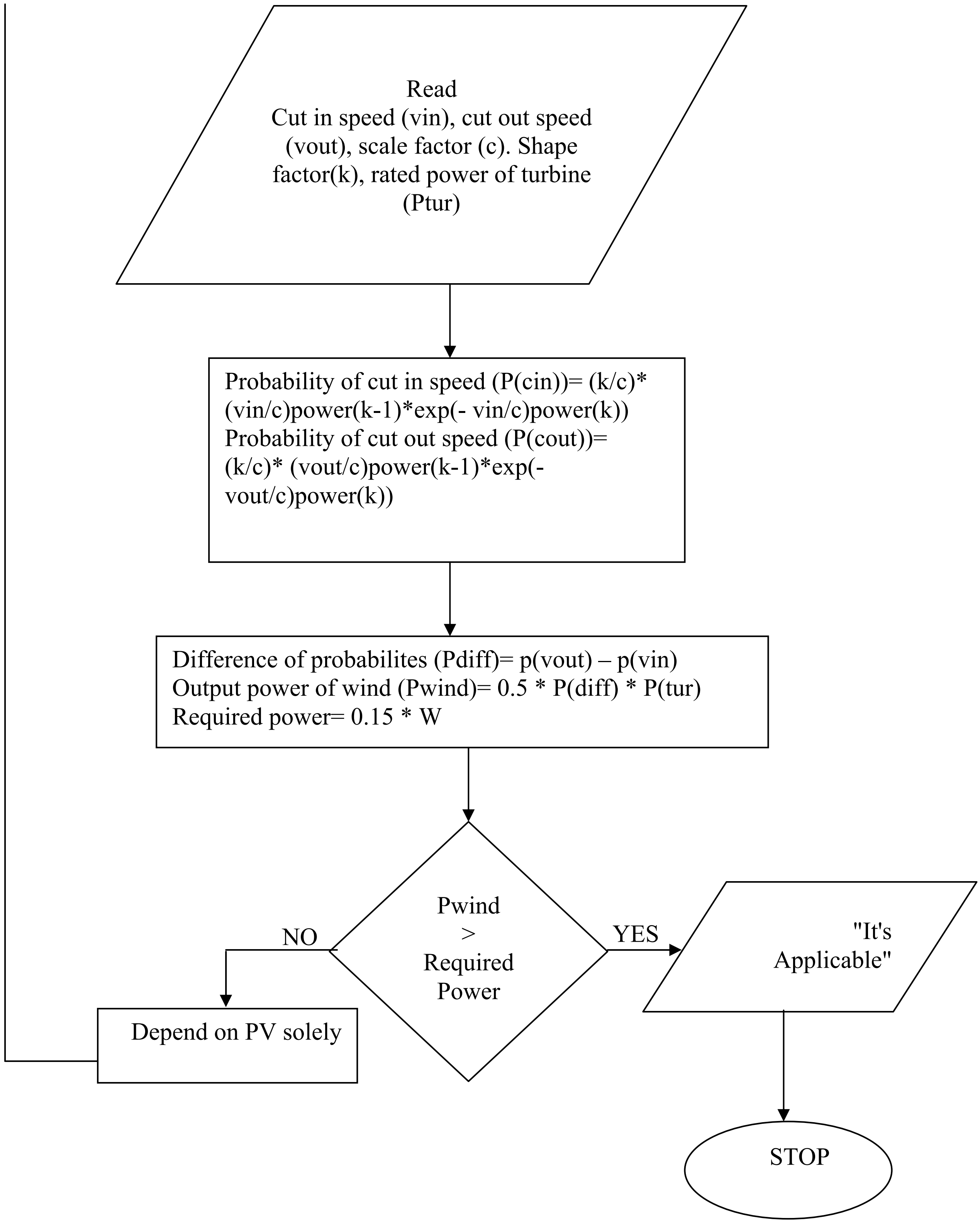


Figure 6.1 Flow chart of JAVA language code

Chapter Seven

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Results and Discussion

Chapter Seven

Results and Discussion

7. Introduction

This chapter exhibits the results obtained in the form of tables and figures, results include solar and wind parameters and hybrid system design values.

7.1 Solar energy results

Table 7.1 shows the summary of the values of solar radiation for all selected sites during the year.

Table 7.1 Solar radiation for all selected sites along the year months (Wh/m^2)

Month	Amman	Aqaba	Ajloun	Alkarak	Dead Sea	Irbid
Jan	3301	3301	3302	3297	3298	3297
Feb	3453	3457	3407	3457	3461	3460
Mar	3651	3649	3653	3653	3653	3653
Apr	3953	3798	3814	3807	3811	3813
May	3950	3941	3958	3957	4115	3958
Jun	4072	4066	4082	4078	4077	4081
Jul	4127	4119	3959	4130	4128	4131
Aug	4028	4238	4248	4246	4246	4248
Sep	4265	4269	4291	4272	4285	4290
Oct	4267	4252	4282	4278	4272	4280
Nov	4255	4236	4269	2263	4258	4267
Dec	4241	4226	4251	4251	4243	4250

Figures 7.1 and 7.2 shows the distribution of hourly solar radiation of all selected sited during January and July months respectively.

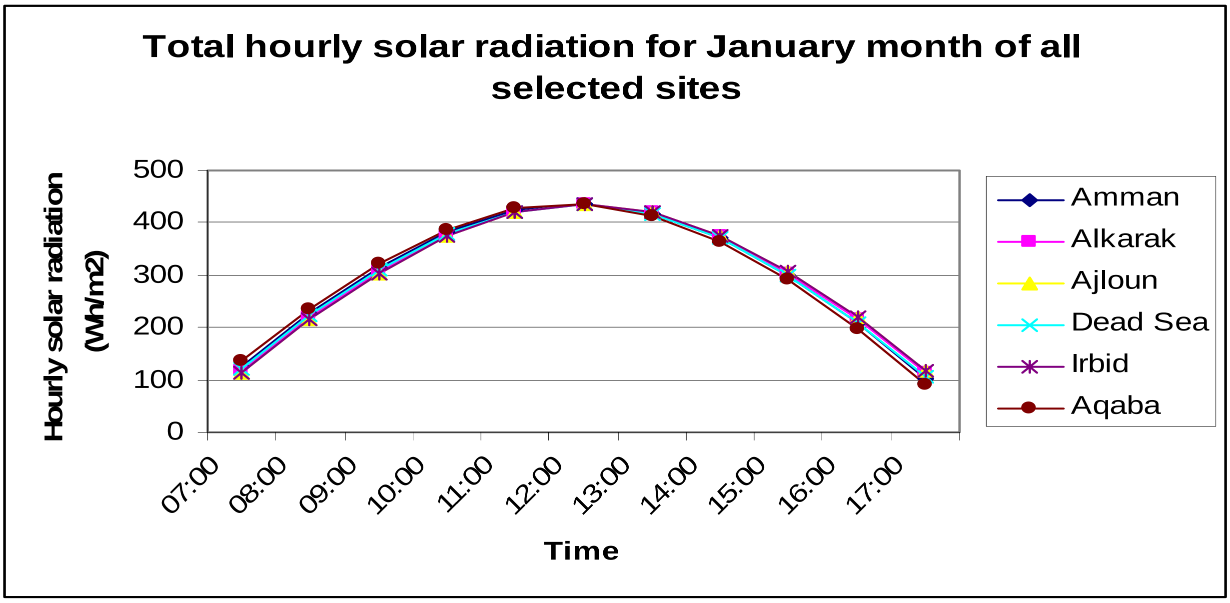

Figure 7.1 Hourly solar radiations for January month for all selected sites.

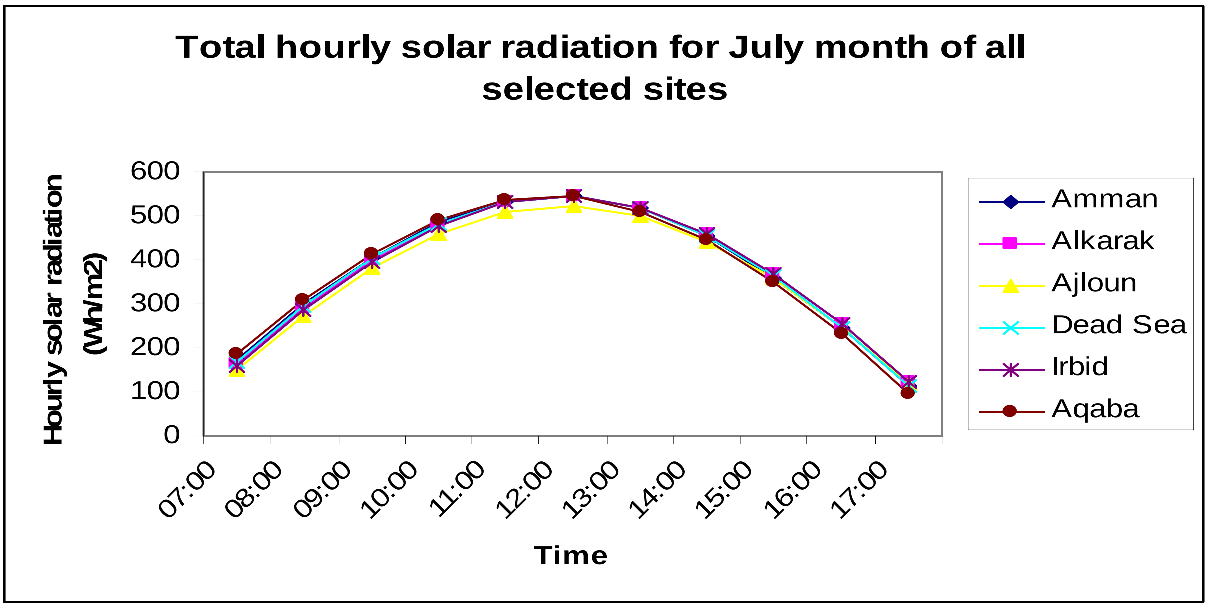

Figure 7.2 Hourly solar radiation for July month for all selected sites.

7.2 Output power of 1 m^2 of the PV cells:

Based on the calculated amount of hourly solar radiation, and by using the equation 5.2 of the mathematical model of the PV cells, the following are some of used assumptions to find the output power of 1m^2 of photovoltaic cells.

- Assume that the efficiencies were as follows:

- efficiency of photo voltaic cells which they are monocrystalline = 18%
- efficiency of array = 90%
- efficiency of connection = 75%
- efficiency of charger = 90%
- efficiency of inverter = 90%

Table 7.2 shows the output power from 1m^2 of photo voltaic cells of all selected sites during the months of the year.

Table 7.2: The output power from 1m^2 of photo voltaic cells for all months of all sites (Wh/day/m^2)

Month	Amman	Aqaba	Ajloun	Alkarak	Dead Sea	Irbid
Jan	324	324.8	324.9	324.4	324.5	324.4
Feb	339.8	340.2	335.2	340.2	340.6	340.5
Mar	359.3	359.1	359.5	359.5	359.5	359.5
Apr	389.0	373.7	375.3	374.6	375.0	375.2
May	388.7	387.8	389.5	389.4	404.9	389.5
Jun	400.7	400.1	401.7	401.3	401.2	401.6
Jul	406.1	405.3	389.6	406.4	406.2	406.5
Aug	396.4	417.0	418.0	417.8	417.8	418.0
Sep	419.7	420.1	422.2	420.4	421.7	422.2
Oct	419.9	418.4	421.4	421.0	420.4	421.2
Nov	418.7	416.8	420.1	222.7	419.0	419.9
Dec	417.3	415.9	418.3	418.3	417.5	418.2

Figure 7.3 shows the distribution of the generated power by photo voltaic cells during the year for all selected sites.

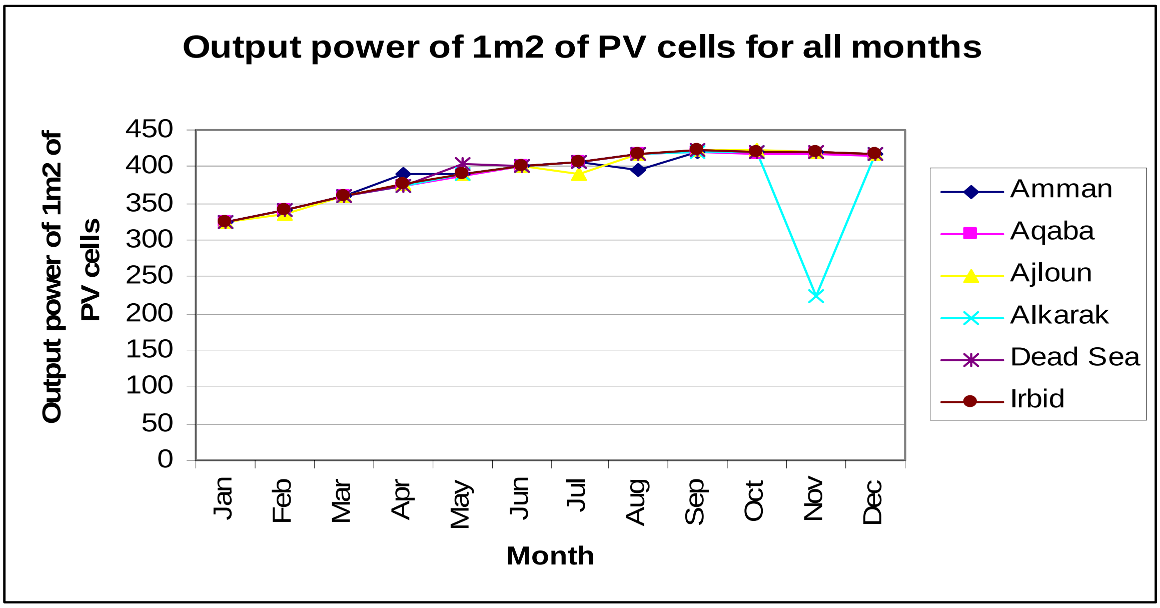

Figure 7.3 the output power of PV cells during the year of the selected sites.

7.3 PV system design:

Table 7.3 shows the main specifications of the used PV.

Table 7.3 PV Modules Specifications

Electrical data	Values
Nominal power (Wp)	150
Voltage at nominal power	18.28
Current at nominal power	8.21
Open circuit voltage	22.68
Short circuit current	8.78
Module efficiency	15%

7.3.1 PV array sizing:

$\eta_t = \eta_{pv} * \eta_{controller} * \eta_{wires} * \eta_{bat} = 0.9*0.9*0.95*0.85 = 65\%$

$$Wt = \frac{W}{\eta_t} = \frac{9000}{0.65} = 13846 \text{ Wh/day}$$

Where:

Wt: is the total power demand required as output of the PV array (Wh/day).

- **The number of required panels.**

$$\text{No. of required modules} = \frac{Wt}{\text{Effective sunshine period} * (150 / \sqrt{\text{٢}})} = \frac{13846}{5 * (150 / \sqrt{\text{٢}})}$$

$$= 26 \text{ modules}$$

No. of required modules for Alkarak, Irbid and Ajloun = 22 modules.

7.3.2 Number of storage batteries:

It was necessary to decrease energy use in such days to 4 kWh as shown in table 5.5. The required number of batteries to store for 24 hours supply according to the specifications in the same table is 6 batteries.

7.4 The inverter power:

The inverter capacity will be, equal to 2.1 kW

Table 7.4 shows that it is Applicable to use wind turbines only on three sites: Alkarak, Irbid and Ajloun.

Location	No. hours per year	No. hours per day	Output power(Wh/day)	Applicability
Alkarak	2102	5.75	3595	Applicable
Irbid	3994	10.9	2965	Applicable
Ajloun	2698	7.39	3220	Applicable

Table 7.4 wind results for three sites.

Other sites proved non Applicable wind energy use. So, it will depend solely on PV energy

As shown in table 7.4, the expected daily output is higher than the required 15% of the daily load which was assigned for the wind power. The wind power required is 15% of the daily load i,e 1.35kWh, the extra expected wind energy output can cover unexpected whether changes wind this caused us in the design not to select smaller wind turbine.

7.5 Wind output energy of the Applicable sites during the year months

According to the calculation of feasibility, we will here calculate the output power for all months of year of the most Applicable sites.

Figures 7.4, 7.5, and 7.6 show the output power of all Applicable sites during the months.

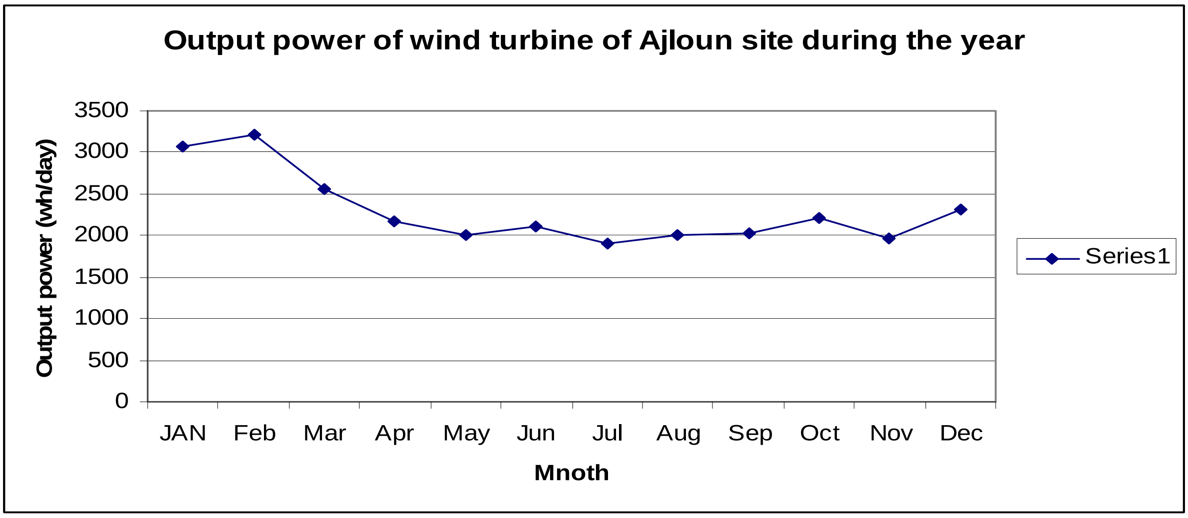

Figure 7.4 output power of wind energy for Ajloun site during the months of the year (Wh/day).

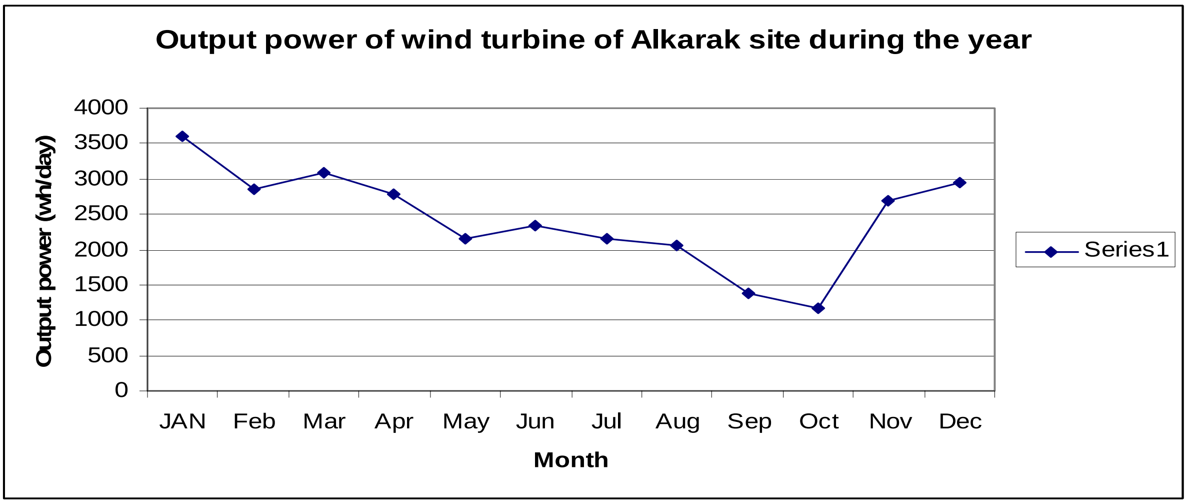

Figure 7.5 output power of wind energy for Alkarak site through the months of the year (Wh/day).

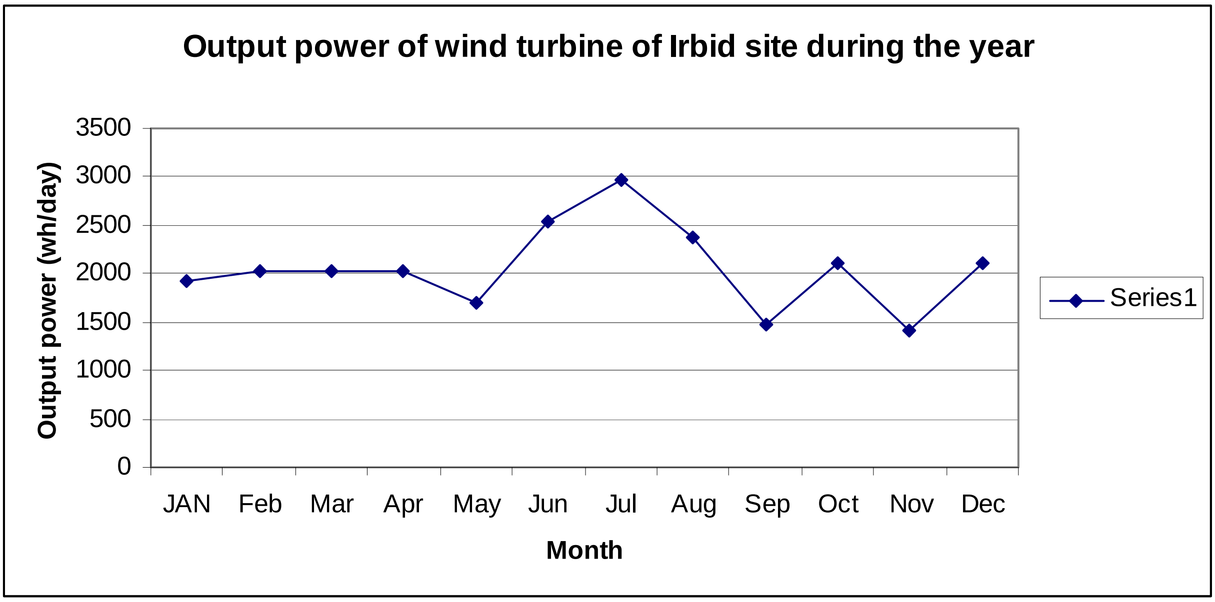

Figure 7.6 output power of wind energy for Irbid site through the months of the year (Wh/day).

The three figures show that in Alkarak and Ajloun the winter wind velocity and power output are higher than that of any other season, while in Irbid the summer wind velocity and power out put are higher than any other season.

Chapter Eight

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Economic Study

Chapter Eight

Economic Study

8. Calculations of annual saving:

Since that the electricity consumption of the assumed house was 9000Wh/day then the monthly consumption of electricity will be 9000*30 = 270 kWh/month which is considered to be of the second category of the consumption categories and so the tariff of 1 kWh equals to 72 fils.

Table 8.1 shows the calculated annual saving of both wind and solar energies.

Table 8.1 Calculations of annual savings of both wind and PV energies.

	Daily consumption (kwh/day)	Monthly consumption (kwh/month)	Wind energy (W)	PV cells energy (W)	Annual savings of wind turbine (JD/year)	Annual saving of PV cells (JD/year)
Amman	9	270	N.F	9000	-	233.3
Aqaba			N.F	9000	-	233.3
Ajloun			3220	5780	83.4	149.8
Alkarak			3595	5405	93.1	140.1
Dead sea			N.F	9000	-	233.3
Irbid			2965	6035	76.8	156.4

8.1 Calculations of simple payback period (SPP):

The following are the calculation of simple pay back period, the cost of hybrid system installation reaches approximately 8100$ (Philadelphia solar energy company) which is equal to 5735 JD, such that 7000$ (4956 JD) is for PV installation and approximately 1100$ (780 JD approximately) of wind turbine installation.

Table 8.2 shows the final results of simple pay back period calculations.

Table 8.2 the calculations of simple pay back period of all selected sites.

location	Cost (JD) of wind turbine	Cost of PV (JD)	Annual savings (wind turbine)(JD/year)	Annual saving(PV) (JD/year)	SPP(wind turbine) (years)	SPP (PV) (years)
Aqaba	-	4956	-	233.3	-	21.2
Irbid	780	4956	76.8	156.4	10.1	31.6
Ajloun	780	4956	83.4	149.8	9.3	33
Amman	-	4956	-	233.3	-	21.2
Dead sea	-	4956	-	233.3	-	21.2
Alkarak	780	4956	93.1	140.1	8.3	35.3

From the previous table, we note that the simple pay back periods are very large.

Chapter Nine

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Conclusions and Recommendations

Chapter Nine:

Conclusions and Recommendations

9. Conclusions:

From this study a set of conclusions can be made as follows:

1- The measurements of wind energy showed that the locations through out Jordan have different mean wind speeds along the year months.

2- Different categories of electricity consumption were calculated, the calculations appeared that the maximum consumption of electricity approaches 9 kWh/day.

3- The percent of wind energy supply was assumed to be 15% of the total supplied energy, so this percent reflected on the required area of PV cells with percent 15% also.

4- The calculations revealed that Alkarak, Irbid, and Ajloun are the most suitable sites that can be used to construct wind turbine unit.

5- The variables of PV power out put found negligible between different sights and single design can operate for all sights.

6- The measurements of PV and wind turbines revealed that the simple pay back periods for the sites are 10.1, 9.3, and 8.3 years for Irbid, Ajloun, and for Alkarak sites, respectively. Where as the SPP periods of the PV systems are 31.6, 33, and 35.3 years of the Applicable sites and its 21.2 year for the not Applicable sites.

7-Design of PV system procedures revealed that the number of required modules equals to 22 and the number of required batteries equals to 6 batteries.

9.1 Recommendations:

The following are some of the recommendations based on this research for future work in using wind photovoltaic systems to meet the energy needs in off-grid systems.

1- Extending the investigation for other locations in order to provide summary to all of the potential locations in Jordan for both wind and solar energy. This will lead to put comprehensive plan for wind and solar energy implementation in Jordan, in order to achieve targets that stated in the energy sector strategy.

2- More research is needed to improve the efficiency of photovoltaic modules; increased efficiency will reduce the need to use many modules, eventually reducing the overall cost of photovoltaic systems.

3- The economic benefits should take into consideration the environmental benefits of building a photovoltaic system as opposed to some other generating source.

4- Drawing solar maps, Jordan have many different areas which have different levels of radiation; these maps will help researchers to take decisions to build PV systems in those areas which have enough levels of radiations.

5- Develop a new and more complicated JAVA program which is able to do more calculations related to the hybrid power systems, so the calculations of any equation will be easier than the manual.

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APPENDIX A

****

```
import javax.swing.*;
public class New{
public static void main(){
double inv, batt,ch,pv,area, electricity,con,wires,Vdcs,
Vdcb,SP, Voc, Isc, Ah,DoD, ;
inv=Double.parseDouble(JOptionPane.showInputDialog(
"Enter the efficiency of inverter"));
batt=Double.parseDouble(JOptionPane.showInputDialog(
"Enter the efficiency of battery"));
ch=Double.parseDouble(JOptionPane.showInputDialog(
"Enter the efficiency of charger"));
pv=Double.parseDouble(JOptionPane.showInputDialog(
"Enter the efficiency of pv"));
wires=Double.parseDouble(JOptionPane.showInputDialog(
"Enter the efficiency of wires"));
Vdcs=Double.parseDouble(JOptionPane.showInputDialog(
"Enter the Dc voltage of the system"));
Vdcb=Double.parseDouble(JOptionPane.showInputDialog(
"Enter the Dc voltage of the battery"));
SP=Double.parseDouble(JOptionPane.showInputDialog("Enter
the effective sunlight period"));
Voc=Double.parseDouble(JOptionPane.showInputDialog("Enter
the open circuit voltage"));
Isc=Double.parseDouble(JOptionPane.showInputDialog("Enter
the short circuit current"));
Ah=Double.parseDouble(JOptionPane.showInputDialog("Enter
the Ampere hour of the battery"));
DoD=Double.parseDouble(JOptionPane.showInputDialog("Enter
the depth of discharge of battery"));
double  total_effic =(Pv * batt * wires);
double Wt = (electricity/total_effic);
System.out.println("The total power demand is: "+ Wt);
```

```
double req_Ah= ( Wt/Vdc);
System.out.println( "the required Ah= "+ req_Ah);
double I_tot =(req_Ah/SP);
double series_pan= (Vdcb / Voc );
double parallel_pan= ( I_tot / Isc);
double tot_pan= ( series_pan * parallel_pan);
double E(dh)=req_Ah / DoD);
double parallel_bat= (Vdcb /Vdc);
double series_bat= (E(dh) / Ah);
double tot_bat= ( series_bat * parallel_bat);
double c,k;
c=Double.parseDouble(JOptionPane.showInputDialog("Enter
the value of c"));
k=Double.parseDouble(JOptionPane.showInputDialog("Enter
the value of k"));
double cut=
Double.parseDouble(JOptionPane.showInputDialog("Enter the
value of cut in speed"));
double rate=
Double.parseDouble(JOptionPane.showInputDialog("Enter the
value of  annual rated speed"));
double power=
Double.parseDouble(JOptionPane.showInputDialog("Enter the
wind turbine rated power"));
double  percent= electricity*0.15;
double propability1=  (k/c)*Math.pow((cut/c),(k-
1))*Math.exp(-1*Math.pow((cut/c),k));
double propability2=  (k/c)*Math.pow((rate/c),(k-
1))*Math.exp(-1*Math.pow((rate/c),k));
double calculate_propability=propability2 - propability1;
System.out.println( "the number of hours per year= "+
(calculate_propability*8760));
System.out.println( "the number of hours per day = "+
((calculate_propability*8760)/365));
```

```
double cc=0.5 *power * (rate - cut);
System.out.println( "the output power "+ cc);
if (cc>= percent)
System.out.println( "it's Applicable ");
else
System.out.println("it's not Applicable ");

     }
}
```

برمجة بالحاسوب ودراسة أداء وجدوى إستخدام نظام هجين لتزويد الطاقة (الطاقة الشمسية وطاقة الرياح) في التطبيقات المنزلية

إعداد
بنان محمد الكساسبة

المشرف
الأستاذ الدكتـ ـ ـور محمود حمـ ـ ـاد

ملخص

الطاقة المتجددة حل جذاب لتحديات الطاقة العالمية. حيث تعتبركلا من الطاقة الشمسية وطاقة الرياح من أفضل أنواع الطاقة المتجددة التي تتوفر بكميات كبيرة في الأردن وتعطي الطاقة المطلوبة وبأقل تكلفة ممكنة.

هدفت هذه الدراسة إلى دراسة جدوى استخدام نظام تزويد الطاقة المهجن والمكون من الطاقة الشمسية وطاقة الرياح في الأردن وخصوصا في التطبيقات المنزلية.

ضمت هذه الدراسة كلا من المناطق الآتية: الكرك، عمان، العقبة، البحر الميت ، اربد، عجلون.

ولدراسة جدوى استخدام الطاقة الشمسية تم حساب مقدار الإستهلاك اليومي لأحد بيوت المملكة واعتباره نموذجا تقريبيا لكافة مناطق المملكة وقد أظهرت نتائج الدراسة أن معدل الإستهلاك اليومي هو٩ كيلو واط يوميا أي ما يعادل ٢٧٠ كيلو واط شهريا تقريبا. وكذلك تم حساب الإشعاع الشمسي الساقط لكل منطقة من هذه المناطق ووجد أنه بمعدل ٣.٥ كيلو واط/م^{٢} في الشتاء و ٤.٥ كيلو واط /م^{٢} في الصيف.

أما بالنسبة لطاقة الرياح فقد أظهرت الدراسة أن المناطق الآتية تعتبر الأكثر ملائمة لإنشاء وحدات رياح فيها وهي: الكرك، إربد، وعجلون بمعدل سرعة رياح سنوية ٧.٣٧ ، ٦.٦١ م/ث لكل من إربد، الكرك، وعجلون على الترتيب . وبمعدل طاقة سنوية مولدة 7.09
2965, 3595, 3220 واط لكل من إربد، الكرك، وعجلون على الترتيب.
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